FINAL REPORT ON ACOUSTICALLY TAGGED ATLANTIC SALMON SMOLT SURVIVAL IN THE PENOBSCOT RIVER AND ESTUARY, 2010-2011

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EXECUTIVE SUMMARY

The purpose of this study was to characterize movement rates and survival of acoustically tagged Atlantic salmon (*Salmo salar*) smolts during seaward migration through the Penobscot River and Estuary in 2010 and 2011. A total of 686 Atlantic salmon smolts were acoustically tagged and released in the Penobscot River at 4 locations. Survival was estimated separately for all releases in each year using Cormack-Jolly-Seber (CJS) mark-recapture models in program MARK. Movement rates of Atlantic salmon smolts were faster in reaches of the river that did not contain dams (1.67±0.03 km/h) than in reaches with dams (0.96± 0.05 km/h). Movement rates of hatchery-reared smolts (1.74±.04 km/h) were significantly faster than movement rates of wild smolts (1.07±0.03) in 2010. These results suggest that it may be possible to use only hatchery smolts to quantify dam effects on smolt movement rates in the future based on the similarities in behavioral trends between hatchery and wild smolts. Cumulative survival of acoustically tagged Atlantic salmon smolts ranged from 0.11 to 0.69 in 2010 and 2011 (excluding release mortality), depending on stocking location. When reach-specific survivals of Atlantic salmon smolts were standardized by the distance of reaches, mortality per kilometer was higher in reaches containing dams (0.026 ±0.008) than in unimpounded reaches (0.008±0.004),

and was different between 2010 (0.014±0.003) and 2011(0.005±0.001). Mortality of Atlantic salmon smolts was observed at four dams that were previously undocumented. Loss at three dams in the upper Piscataquis River was comparable to dams in the Penobscot River. Information on about wild smolt survival through Weldon Dam suggests that the dam has a comparatively greater influence on smolt mortality than all but one dam (West Enfield) in the Penobscot River.

INTRODUCTION

Juvenile anadromous fishes require uninterrupted passage through riverine habitats in order to successfully reach the marine environment. During migration, immediate or delayed mortality may result from predation, direct injury from turbines or other dam-related structures (Ruggles 1980; NMFS 2000). Migratory delays caused by physical or behavioral barriers may further increase predation risk (Nettles and Gloss 1987; Blackwell et al. 1997) or cause poor synchrony of physiological tolerance to salinity (McCormick et al. 1999) possibly increasing estuarine mortality (Budy et al. 2002; Ferguson et al. 2006).

During seaward migration, Atlantic salmon (*Salmo salar*) smolts are exposed to a host of new environments and trophic interactions, and they undergo changes with respect to behavior, morphology, and physiology (McCormick et al. 1998). Anthropogenic factors can influence the timing and speed of migration, the physiological status of Atlantic salmon smolts, and ultimately the survival of smolts during emigration from freshwater (McCormick et al. 1998).

Anthropogenic changes to in-river conditions such as dams and pollution have been shown to influence survival of downstream-migrating smolts (Ruggles and Watt 1975). As an example, changes in flow-regimes upstream of dams, such as head ponds and reservoirs can delay migration (Holbrook et al. 2011), resulting in asynchrony of migration (Spicer et al. 1995; McCormick et al. 1998) and increased exposure to predators (Blackwell et al. 1997; Blackwell and Juanes 1998) or loss of smolt characteristics (Bley and Moring 1988). In addition to mortality due to increased predation risks and desmoltification, dams are known sites of mortality resulting from physical injury (Stier and Kynard 1986; Nettles and Gloss 1987; Raymond 1988; Skalski et al. 2009).

The transition by Atlantic salmon smolts into the estuary is a period of high mortality (Gudjonsson et al. 2005; Svenning et al. 2005). This period is marked by high predation risk, new food sources, physiological stresses, and increased variability in habitat such as tidal fluctuations (McCormick et al. 1998; Aas et al. 2011). The risks posed to smolts in the estuary are made more complex by influences such as climate change and shifts in nutrients and contaminants (Mills 1989; Rosseland and Koglund 2011). The Penobscot Estuary spans approximately 15 km from the mouth of the estuary to the head of tide (Haefner 1967). Near-uniform conditions prevail at the head of the estuary (Imhoff and Harvery 1972), while the middle estuary is characterized by considerable mixing of fresh and salt water (Seiwell 1932), and a high degree of stratification exists in the lower estuary (Imhoff and Harvey 1972). The middle Penobscot Estuary is considered to be a critical zone for fish survival due to low pH, high turbidity, and low dissolved oxygen concentrations (Haefner 1967).

The goal of this study was to characterize mortality and movement rates of wild- and hatchery-reared Atlantic salmon in the Penobscot River. In order to achieve this goal, we acoustically tagged Atlantic salmon smolts at for different location s in the Penobscot River in 2010 and 2011. We used a stationary array of acoustic receivers to collect location data about downstream-migrating smolts. Location data were used to determine relative rates of movement and to estimate survival of Atlantic salmon smolts during migration.

METHODS

Acoustic-receiver array

Autonomous acoustic receivers were deployed in the Penobscot River prior to the start of the Atlantic salmon smolt run each year of the study by the University of Maine, in cooperation with USGS and NOAA. The number and type of receivers deployed in the Penobscot River watershed varied by year. Up to 178 acoustic receivers were deployed in a given year, providing detection coverage from release sites through the outer Penobscot Bay (Figure 1). Coverage of the acoustic array extended from the Town of Abbot on the Piscataquis River and the Town of Medway on the East Branch Penobscot River downstream through the Penobscot Bay at Owl's Head and Mullen Head. Acoustic receivers deployed in the Penobscot River and Penobscot Estuary were moored to cement blocks on the river bottom. Acoustic receivers deployed in the Penobscot Bay were moored approximately 10 m below the surface of the water. All receivers were equipped with omnidirectional hydrophones that scanned constantly at 69 hz. Multiple receivers were deployed where the width of the river exceeded the detection range of acoustic receivers, and detections for all receivers at such locations were pooled as single encounter events for survival analyses.

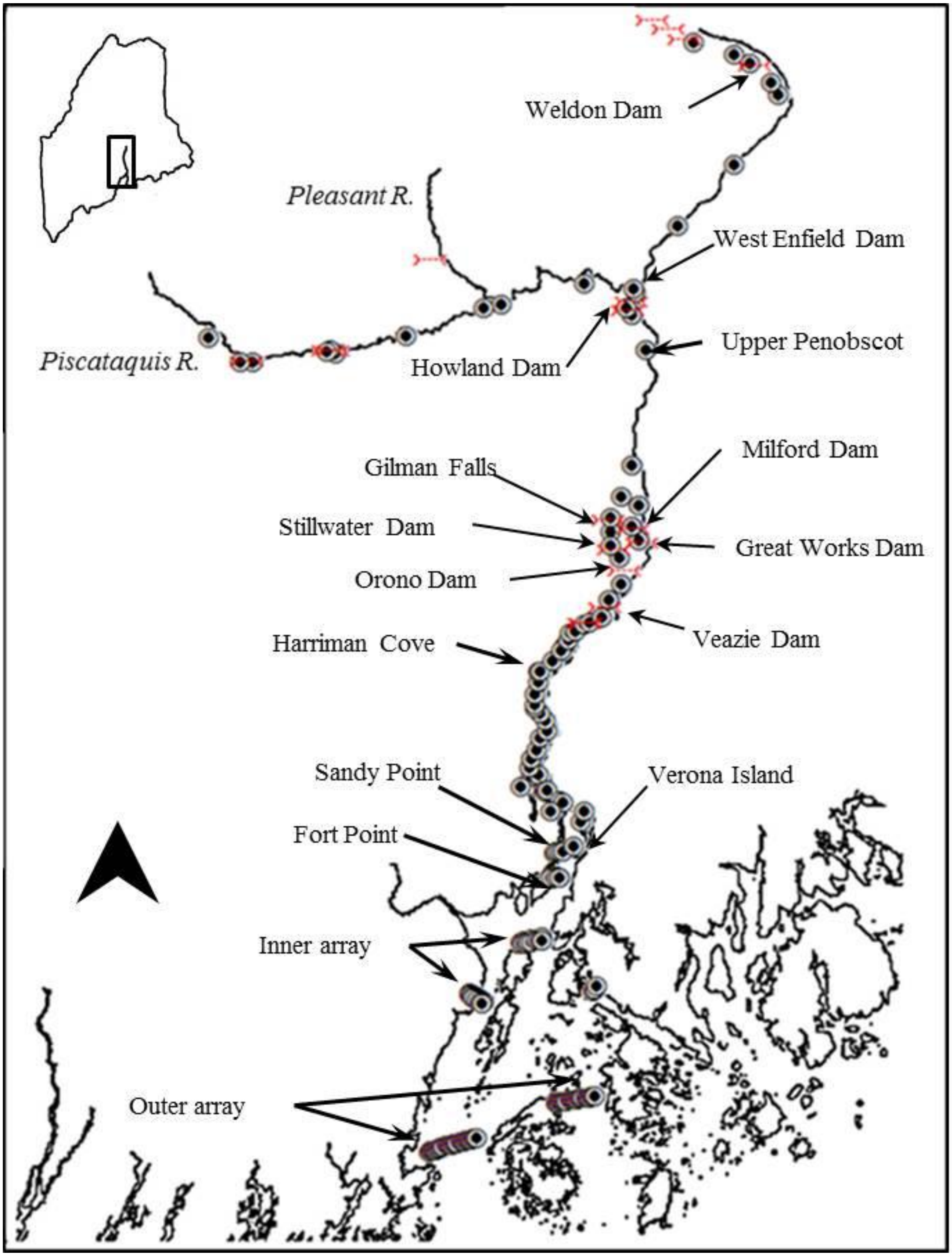

Figure 1.- Map of the Penobscot River, Estuary, and Bay showing the locations of acoustic receivers (◉), and dams (›--‹) in 2011.

Acoustic tagging

A total of 776 Atlantic salmon smolts was acoustically tagged and released in the Penobscot River in 2010 and 2011 (Table 1). All Atlantic salmon smolts captured for tagging were anaesthetized using a buffered solution of MS-222 (100 mg/L, $NaCO_3$, pH=7.0) prior to surgery. After anaesthetization, fork length (FL, mm) of Atlantic salmon smolts was measured, and each fish was weighed to the nearest gram. Atlantic salmon smolts were placed ventral side up in a v-shaped saddle and a small (1-cm) incision was made, offset slightly from the ventral line. An acoustic tag was inserted through the surgical incision, and the wound closed with two interrupted knots using non-absorbable, vicryl sutures (Ethicon, Somerville, New Jersey). Acoustic tags used in this study were models V7-2X, and V9-6X from Vemco (Vemco Ltd., Halifax, Nova Scotia). The range of expected battery life of tags used in this study was 69-82 d. Tags were programmed with unique acoustic "pinger" patterns that permitted identification of individual tags upon detection. Atlantic salmon smolts were allowed to recover in oxygenated water before being transferred to a holding tank. All fish were observed to recover completely in the holding tank before release into the river. Atlantic salmon smolts were released at six different locations depending on the year and location of capture (Table 1).

Table 1.- Number of Atlantic salmon acoustically tagged in the Penobscot River (fresh water) 2010-2011.

Year	Release site	Origin	Number Released
2010	Abbot	Wild	75
	Milo	Hatchery	100
	Passadumkeag	Hatchery	100
	Weldon head pond	Wild	75
2011	Abbot	Wild	75
	Milo	Hatchery	100
	Passadumkeag	Hatchery	100
	Weldon head pond	Wild	61

Movement rates. - Movement rates were calculated between individual monitoring sites during 2010. To provide direct comparison among river sections, the movement rate (R_{ij}) was calculated for each smolt between any two monitoring sites,

$$R_{ij} = L_{ij}{T_{ij}}^{-1}$$

where L_{ij} is the distance (in RKM) between upstream site i and downstream site j, and T_{ij} is the time difference (in hours) between first detections at sites j and i. Similar detection range at each site is assumed. The effects of reach type (dams or no dams) and smolt origin (wild or hatchery) on movement rate (R_{ij}) were tested using one-way analysis of variance (ANOVA; Zar 1999). Tukey-Kramer pair-wise comparisons of means were used to determine differences between reach types and smolt origin. Because the head ponds at most dams in the Penobscot River comprise short reaches upstream of dams, movements through head ponds could not be consistently separated from movements through reaches containing dams, thus reaches containing dams in the following analyses also contain head ponds. Statistical significance was inferred at α=0.05 for all tests (Zar 1999).

Modeling Atlantic salmon smolt survival

The survival estimates developed here should be useful for informing present population models as starting values, and should be "used" with the understanding that a more-refined approach to model development (i.e. use of multi-state models and incorporation of factors that covary with survival) will produce more-precise and more-accurate estimates of survival in the future. Because of the limitations on precision due to current model structure, differences in survival between fish of different origin (i.e. hatchery or wild), and fish released at different sites or times were not tested for in survival models. Instead, we present general trends in survival that will be examined in more detail in the future.

Atlantic salmon smolt survival 2010-2011 was characterized using single-state, Cormack-Jolly-Seber (CJS) mark-recapture models. Individual location histories were constructed for each fish, and the histories were used to model survival and detection probabilities each year in program MARK. In both years, the best models of survival were those that allowed both survival and detection probabilities to vary by interval. We used pooled-location events to model Atlantic salmon smolt survival in 2010 and 2011 (Figure 2). Since the probability of survival cannot be isolated from detection probability in the final interval of CJS models, survival estimates between the inner array and outer array in Penobscot Bay are the products of survival and detection probabilities (λ). Estimates of λ are not presented in the results due to lack of precision.

All estimates of survival were converted to total reach mortalities (M_i) after parameter estimation, except for estimation of cumulative survival probabilities. Cumulative survival probabilities were estimated within release groups each year by multiplying the survival of smolts through all intervals except the final interval (λ). Cumulative survival probabilities are reported that include release mortality (Appendices B and C) and that do not (Appendices D and E). The standard error of cumulative survival estimates to each interval was estimated using the Delta method. The delta method uses information about the variability in survival within reaches and among reaches to approximate the variance of cumulative survival as a function of reach-specific, maximum-likelihood estimates of survival.

We transformed maximum-likelihood estimates of reach mortality (M_i) into instantaneous mortality rates standardized by distance (km) in order to standardize mortality rates between reaches. Mean instantaneous mortality rates (Z_{di}) for each reach in each year were used to determine differences between years, and differences in mortality between impounded and unimpounded reaches were tested using two-sample *t*-tests (Zar 1999). Statistical significance was inferred at $\alpha=0.05$ for all tests. Differences between total reach mortality (M_i) and instantaneous mortality (Z_{di}) are elaborated on in Appendix F.

Assessing model fit

Some measure of how well a linear model of survival fits location data is useful to determine whether or not the models accurately represent trends in the data. To assess model fit, we estimated the over-dispersion parameter (a measure of candidate model departure from the "true" model), $\hat{C}$, for the each full model using the bootstrap goodness of fit and median $\hat{C}$ goodness of fit tests in MARK. The "full" model is the most-general model used to fit the data, and as such provides a useful baseline for understanding the fit of all other candidate models of survival. Generally speaking, if the full model fits the data well, then all smaller models nested within that candidate model set will also fit the data well. To estimate the over-dispersion parameter using the bootstrap procedure ($\hat{C}_{bootstrap}$), the observed full model deviance is divided by the mean deviance among 200 simulated deviances. The median $\hat{C}$ procedure uses logistic regression to estimate $\widehat{C}_{median}$. To be conservative, we use the larger of $\hat{C}_{bootstrap}$ and $\hat{C}_{median}$ as an estimate of $\hat{C}$. Based on the initial results, variances were not adjusted for 2010 or 2011.

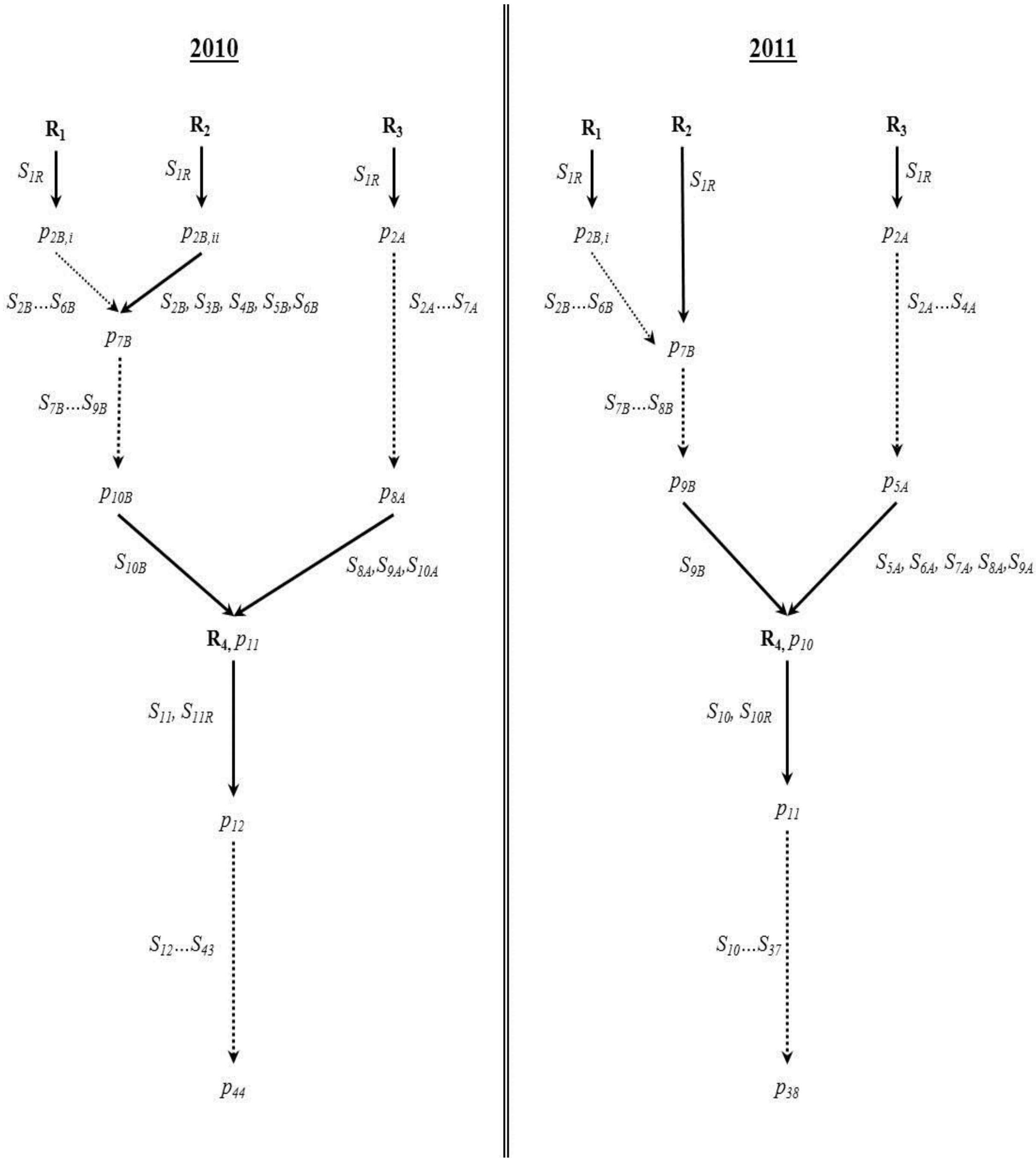

Figure 2.-Schematics of the pooled locations (p_{ih}) used to model Atlantic salmon smolt survival through the Penobscot River in 2010 and 2011. Dotted arrows indicate sections in which multiple reaches were collapsed to conserve space, and where all reach-specific survival parameters (S_{ih}) and detection probabilities (p_{ih}) were estimated between locations. For example, in 2010 all S_{ih} and p_{ih} between $p_{2B,i}$ and p_{7B} were estimated for $S_{2B}...S_{6B}$. Solid arrows with condensed, reach-specific survival estimates separated by commas indicate intervals in which only one survival rate (S_{ih}) was estimated. For example, only one survival rate was estimated for the interval between $p_{2B,ii}$ and p_{7B} in 2010.

RESULTS

Movements of Atlantic salmon smolts

Distances of reaches used to estimate survival of Atlantic salmon smolts 2010-2011 and smolt movement rates in 2010 are provided in Tables A.1-A.4 in Appendix A. Mean movement rate of downstream-migrating Atlantic salmon smolts in the Penobscot River (2010) was 1.46 km/h. Movement rates were higher in reference reaches than reaches containing dams ($F=172$, $df=1$, $p<0.001$) and were lower for wild fish than for hatchery fish ($F=186$, $df=1$, $p<0.001$). Interactions between fish origin and reach type were also significant ($F=19$, $df=1$, $p<0.001$; Figure 3).

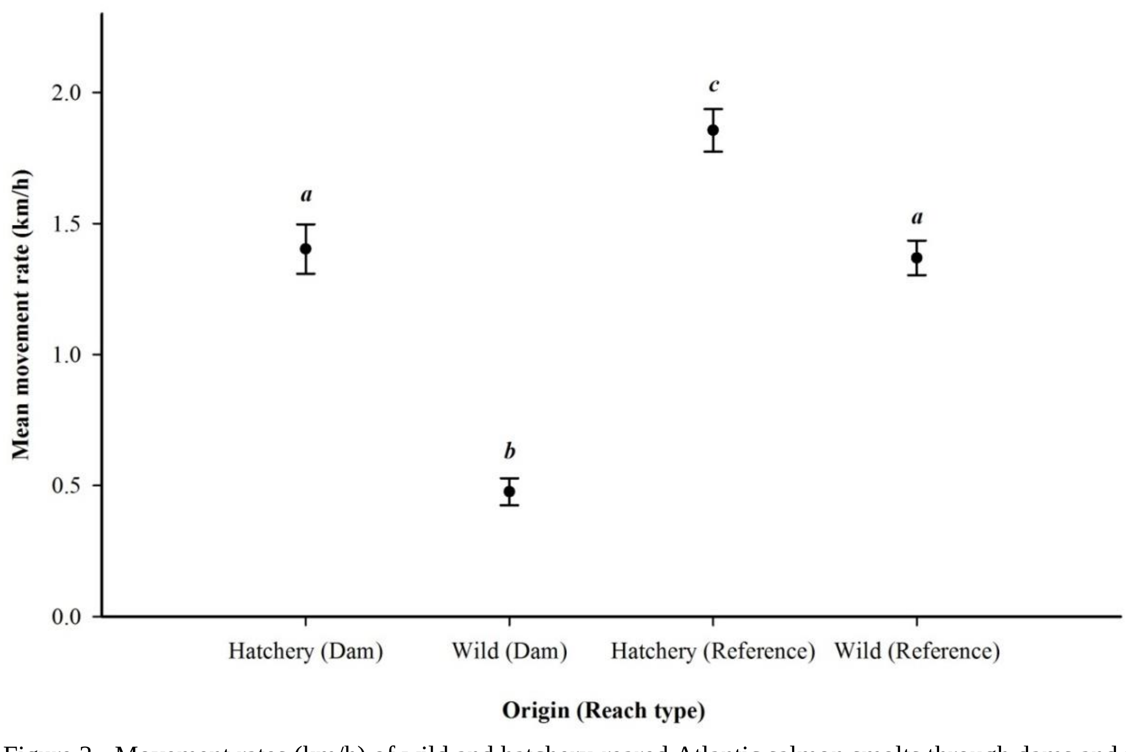

Figure 3.- Movement rates (km/h) of wild and hatchery-reared Atlantic salmon smolts through dams and reference reaches (±2SE) in the Piscataquis and Penobscot Rivers in 2010. Levels not connected by the same letter are significantly different.

Mortality of Atlantic salmon smolts

Mean Atlantic salmon smolt mortality (per km) was lower in 2011 than in 2010 ($t=^{-}2.89$, df=66, p=0.005; Figure 4). Similarly, cumulative survival of wild smolts released at Abbot (±SE) increased from 0.18 (±0.05) in 2010 to 0.68 (±0.05) in 2011 (excluding release mortality; Tables E.1 and E.2). We did not observe other significant increases in cumulative survival by release site between 2010 and 2011 (Figures D.3-D.8). Cumulative survival probabilities, with and without release mortality, to each interval and associated standard errors are presented with reach-specific survival rates for each release cohort in Appendices B-E.

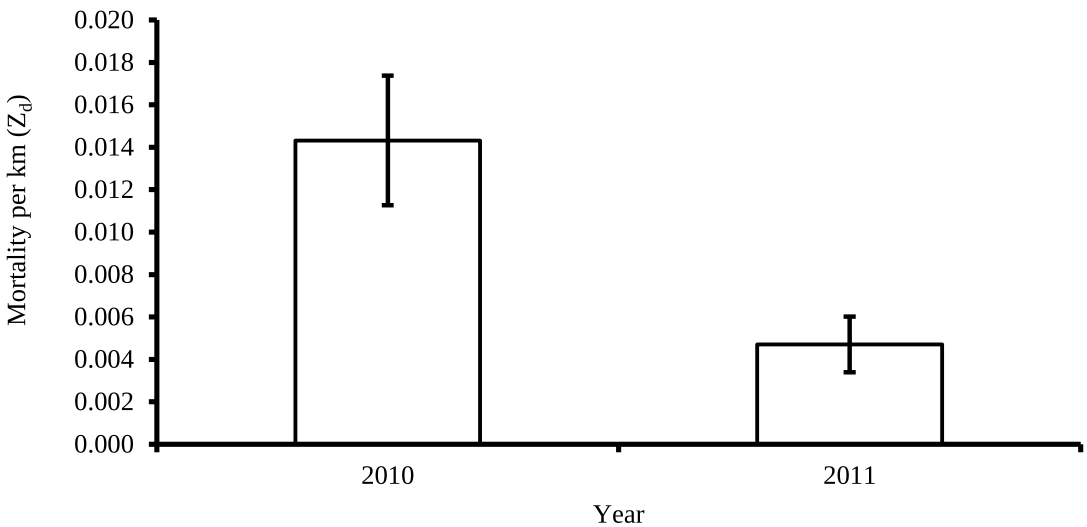

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Figure 4.- Mean mortality per kilometer (Z_d) of Atlantic salmon smolts acoustically tagged and released in the Penobscot and Piscataquis Rivers 2010-2011 (±SE).

Mean Atlantic salmon smolt mortality per kilometer was lower in reference reaches than in reaches containing dams ($t=^{-}2.304$, df=42, p=0.026) when Z_{di} was pooled among reference reaches and among impounded reaches in 2010 and 2011 (Figure 5). In 2010, instantaneous rates of Atlantic salmon smolt mortality (Z_{di}) were above 0.05 in 4 reaches of the river. The four reaches with $Z_{di}>0.05$ in 2010 were Great Works head pond (0.10), Great Works Dam (0.05), the estuary reach between Winterport and Drachm Point (0.08) and the estuary reach between

Chipman Falls and Bowden Point (0.09). The highest rates of instantaneous mortality in 2011 were observed at Weldon Dam (0.04), West Enfield Dam (0.02), and at Frankfort Flats in the lower estuary (0.01).

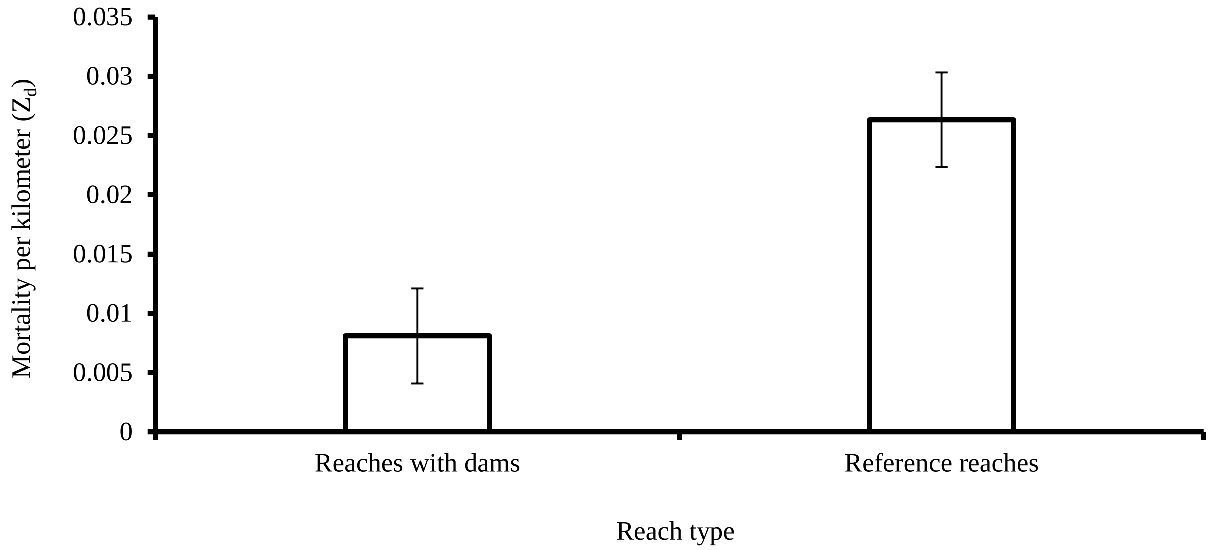

Figure 7.-Comparison of mean Atlantic salmon smolt mortality per kilometer ($\hat{Z}_d$) in dams and reference reaches (±SE). Instantaneous mortality rates were pooled among 2010 and 2011.

Atlantic salmon smolt mortality varied significantly among intervals in 2010 (Figure 6) and 2011 (Figure 7). In both years of the present study, Howland Dam, Weldon Dam, and West Enfield Dam had the greatest effect on total reach mortalities (M_i) of Atlantic salmon smolts. In 2010, total reach mortality (M_i) was above 0.10 in 5 reaches containing dams: Dover Dam (0.11±0.04), Howland Dam (0.11±0.05), Milford Dam (0.12±0.05), Weldon Dam (0.11±0.02), and West Enfield Dam (0.18±0.06). In 2011, total reach morality (M_i) was above 0.01 in 3 reaches containing dams: Howland Dam (0.09±0.04), Weldon Dam (0.259±0.10), and West Enfield Dam (0.10±0.10). The only estuary reach in which M_t was greater than 0.10 in 2010 was between Winterport and Drachm Point in the middle estuary. Total reach mortality was less than 0.10 in all estuary reaches in 2011.

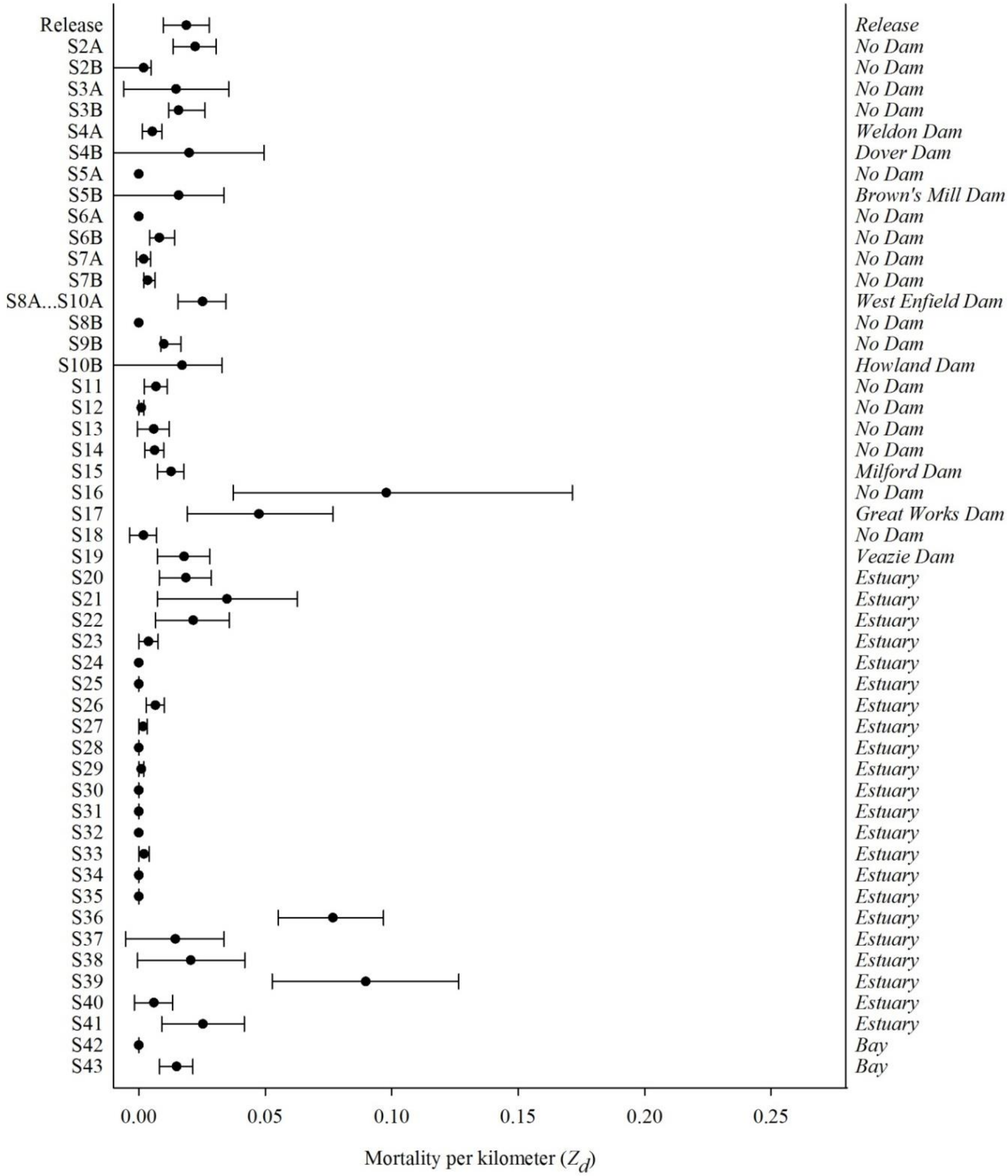

Figure 6.- Mean Reach–specific mortality per kilometer ($\hat{Z}_d$) of Atlantic salmon smolts acoustically tagged and released in the Penobscot River in 2010 (± asymmetrical SE). Release mortality is averaged among all releases.

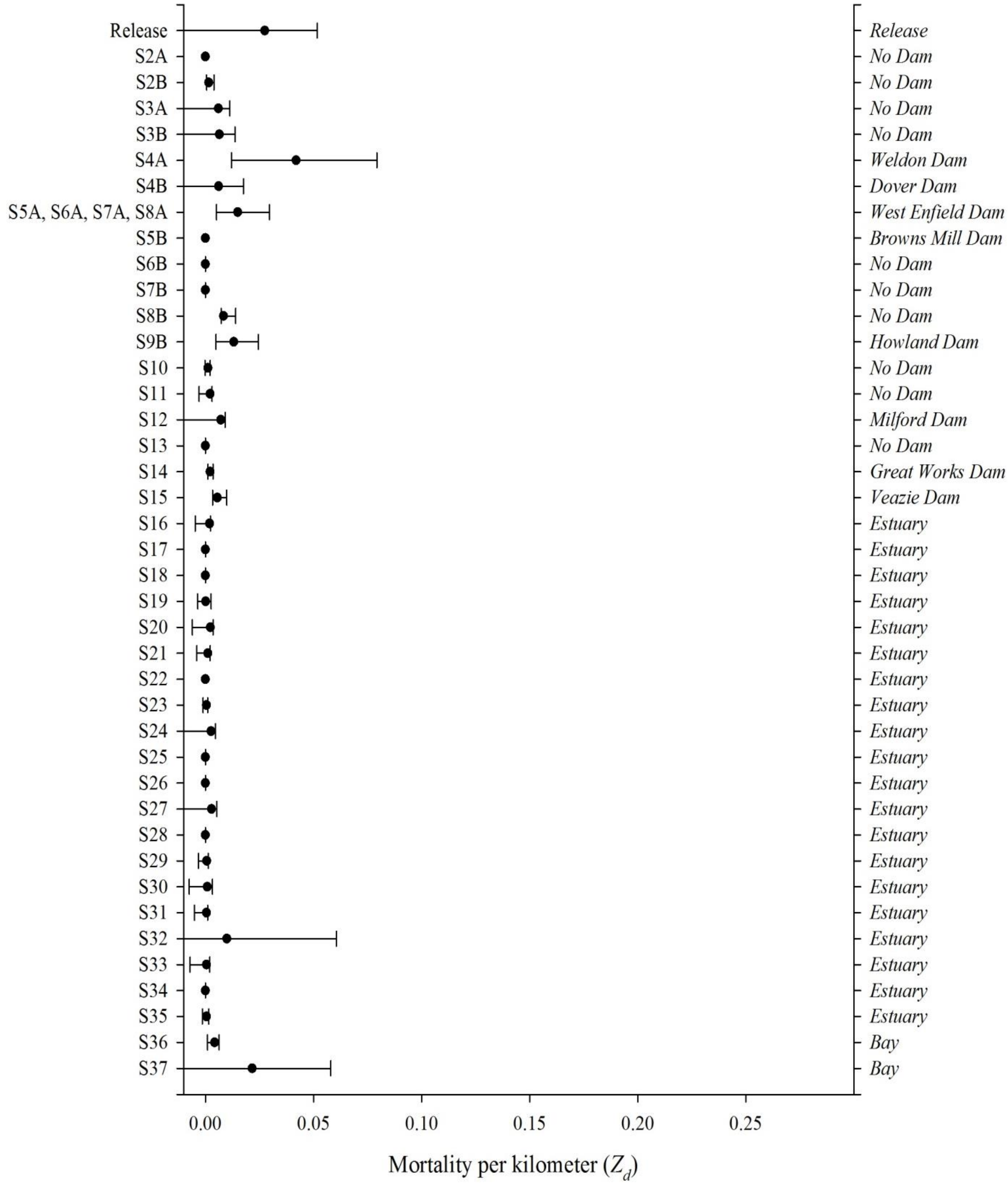

Figure 7.- Reach–specific mortality per kilometer ($\hat{Z}_d$) of Atlantic salmon smolts acoustically tagged and released in the Penobscot River in 2011 (± asymmetrical SE). Release mortality is averaged among all releases.

CONCLUSIONS

Movement rates of hatchery smolts were faster than those of wild smolts in 2010. Movement rates of all smolts were faster through reaches of the river that did not contain dams than through reaches of the river containing dams. The effects of dams on Atlantic salmon smolt movements were similar between hatchery and wild smolts, although the magnitude of dam effects was greater in hatchery smolts due to comparatively higher movement rates for hatchery smolts. These results suggest that hatchery smolts could be used exclusively to quantify the relative impacts of dams on movement rates in the future.

Mortality was elevated in reaches containing dams compared to mortality in reaches without dams. Mortality in reaches without dams exceeded 0.05 per kilometer at only one reach in 2011 (Great Works head pond), and was never higher than 0.05 in 2010. Elevated mortality was observed at all dams in at least one year of the study.

Mortality of wild Atlantic salmon smolts in reaches containing dams that had not previously been studied in the Piscataquis and Penobscot Rivers was elevated compared to reference reaches. The effects of Guilford Dam, Dover Dam, and Brown's Mill Dam on wild Atlantic salmon smolt mortality were quantified in the Piscataquis River for the first time. Our results suggest that mortality at these reaches was variable between years. However, with the exception of Brown's Mill Dam in 2011, all of these dams increased mortality of Atlantic salmon smolts in 2010 and 2011. Loss at the three dams in the Piscataquis River was comparable to other dams in the Penobscot River in this and earlier studies. Wild, Atlantic salmon smolt mortality was also elevated in the reach containing Weldon Dam than in reference reaches in both years. Total reach mortality at Weldon Dam was higher than all reaches except for West Enfield Dam in 2010, and was higher than mortality in any other reach in 2011.

Weldon Dam, West Enfield Dam, and Howland Dam were consistently among reaches with highest mortality in the Penobscot River in 2010 and 2011. The decommissioning of Howland Dam and construction of fish bypass facilities at Howland has the potential to decrease mortality of Atlantic salmon smolts out-migrating from the Piscataquis River. However, Weldon and West Enfield Dams will remain in operation on the Penobscot River. Losses of Atlantic salmon smolts were greatest at West Enfield Dam in 2010 and at Weldon Dam in 2011.

The impact of Milford Dam on smolt survival was highly variable between years. Total loss at Milford Dam was 0.12 (±0.05) in 2010 and 0.05(±0.03) in 2011. If variability in smolt survival at Milford Dam is related to flow conditions in a predictable manner, this information may be useful for informing management decisions in the future. This will become increasingly relevant when Veazie and Great Works Dams are removed and Milford Dam becomes the lower-most barrier to anadromous fish passage in the Penobscot River.

Elevated mortality was observed in 2010 and 2011during salt water entry. Elevated mortality was observed in 2010 at entry into the estuary and in the middle estuary where the influence of salt is most pronounced. In 2011 estuary mortality was highest in the middle estuary near Frankfort Flats. Mortality per kilometer was less than 0.01 in all other estuary reaches.

Appendix A: Average, reach-specific survival and associated statistics for acoustically tagged Atlantic salmon smolts released in the Penobscot and Piscataquis Rivers 2010- 2011.

Table A.1.-Average, reach-specific, fresh-water survival estimates $(\hat{S}_i)$ of Atlantic salmon smolts acoustically tagged and released in the Penobscot and Piscataquis Rivers in 2010.

Interval	$\hat{S}_i$	SE[a]	95% CI[b]	Reach Length (km)	Reach Type
S_R	0.95	0.02	0.87-0.98	5.5	Release
S_{2A}	0.88	0.04	0.77-0.94	5.5	No Dam
S_{2B}	0.99	0.01	0.90-1.00	1.5	No Dam
S_{3A}	0.99	0.02	0.80-1.00	1.0	No Dam
S_{3B}	0.90	0.04	0.81-0.96	12.0	No Dam
S_{4A}	0.96	0.03	0.84-0.99	8.0	Weldon Dam
S_{4B}	0.89	0.04	0.78-0.95	3.3	Dover Dam
S_{5A}	1.00	0.00	1.00-1.00	28.0	No Dam
S_{5B}	0.94	0.03	0.79-0.98	1.5	Brown's Mill Dam
S_{6A}	1.00	0.00	1.00-1.00	1.0	No Dam
S_{6B}	0.95	0.03	0.87-0.98	13.0	No Dam
S_{7A}	0.97	0.04	0.68-1.00	14.0	No Dam
S_{7B}	0.98	0.01	0.94-0.99	21.4	No Dam
S_{8A}, S_{10A}, S_{10A}	0.82	0.06	0.67-0.91	7.8	West Enfield Dam
S_{8B}	1.00	0.00	1.00-1.00	13.8	No Dam
S_{9B}	0.93	0.04	0.77-0.98	11.1	No Dam
S_{10B}	0.89	0.05	0.76-0.95	3.5	Howland Dam
S_{11}	0.96	0.03	0.83-0.99	6.4	No Dam
S_{12}	0.98	0.02	0.87-1.00	20.1	No Dam
S_{13}	0.96	0.04	0.66-0.99	6.4	No Dam
S_{14}	0.92	0.04	0.74-0.97	13.5	No Dam
S_{15}	0.88	0.05	0.75-0.94	9.9	Milford Dam
S_{16}	0.97	0.03	0.87-0.99	0.3	No Dam
S_{17}	0.97	0.02	0.89-0.99	0.7	Great Works Dam
S_{18}	0.99	0.02	0.71-1.00	3.3	No Dam
S_{19}	0.94	0.03	0.83-0.98	3.6	Veazie Dam

[a] Standard error
[b] Profile-likelihood confidence intervals

Table A.2.-Average, reach-specific, estuary and bay survival estimates $(\hat{S}_i)$ of Atlantic salmon smolts acoustically tagged in the Penobscot and Piscataquis Rivers in 2010.

Parameter	$\hat{S}_i$	*SE*	95% CI	Reach Length (km)	Reach Type
S_{20}	0.96	0.02	0.91-0.99	2.1	Estuary
S_{21}	0.97	0.03	0.88-0.99	0.9	Estuary
S_{22}	0.97	0.02	090-0.99	1.6	Estuary
S_{23}	1.00	0.00	0.98-1.00	0.9	Estuary
S_{24}	1.00	0.00	1.00-1.00	1.0	Estuary
S_{25}	1.00	0.00	1.00-1.00	0.7	Estuary
S_{26}	0.98	0.01	0.92-0.99	3.5	Estuary
S_{27}	1.00	0.00	0.97-1.00	2.5	Estuary
S_{28}	1.00	0.00	1.00-1.00	1.7	Estuary
S_{29}	1.00	0.00	0.98-1.00	3.5	Estuary
S_{30}	1.00	0.00	1.00-1.00	0.7	Estuary
S_{31}	1.00	0.00	1.00-1.00	1.3	Estuary
S_{32}	1.00	0.00	1.00-1.00	1.5	Estuary
S_{33}	1.00	0.00	0.98-1.00	1.7	Estuary
S_{34}	1.00	0.00	1.00-1.00	1.5	Estuary
S_{35}	1.00	0.00	1.00-1.00	2.0	Estuary
S_{36}	0.89	0.03	0.84-0.94	1.6	Estuary
S_{37}	0.98	0.02	0.86-1.00	1.2	Estuary
S_{38}	0.98	0.02	0.91-1.00	0.8	Estuary
S_{39}	0.91	0.04	0.83-0.96	1.0	Estuary
S_{40}	0.99	0.02	0.88-1.01	2.6	Estuary
S_{41}	0.98	0.01	0.94-1.00	0.7	Estuary
S_{42}	1.00	0.00	1.00-1.00	9.4	Bay
S_{43}	0.94	0.02	0.85-0.98	4.0	Bay

Table A.3.-Average, reach-specific, fresh-water survival estimates $(\hat{S}_i)$ of Atlantic salmon smolts acoustically tagged and released in the Penobscot and Piscataquis Rivers in 2011.

Parameter	$\hat{S}_i$	*SE*	95% CI	Reach Length (km)	Reach type
S_R	0.84	0.03	0.62-0.90	14.9	Release
S_{2A}	1.00	0.00	1.00-1.00	5.5	No Dam
S_{3A}	0.96	0.04	0.76-0.99	1.0	No Dam
S_{4A}	0.74	0.10	0.50-0.89	37.0	Weldon Dam
$S_{5A...9A}$	0.90	0.10	0.53-0.99	41.8	West Enfield Dam
S_{2B}	0.99	0.02	0.58-1.00	13.5	No Dam
S_{3B}	0.96	0.03	0.84-0.99	1.0	No Dam
S_{4B}	0.96	0.03	0.87-0.99	1.0	Dover Dam
S_{5B}	1.00	0.00	1.00-1.00	15.5	Browns Mill Dam
S_{6B}	1.00	0.00	1.00-1.00	33.0	No Dam
S_{7B}	1.00	0.00	1.00-1.00	14.6	No Dam
S_{8B}	0.94	0.03	0.84-0.98	9.7	No Dam
S_{9B}	0.91	0.04	0.78-0.96	27.8	Howland Dam
S_{10}	0.99	0.01	0.96-1.00	6.4	No Dam
S_{11}	0.99	0.01	0.95-1.00	3.6	No Dam
S_{12}	0.95	0.03	0.87-0.98	3.1	Milford Dam
S_{13}	1.00	0.00	1.00-1.00	0.3	No Dam
S_{14}	0.99	0.01	0.96-1.00	7.7	Great Works Dam
S_{15}	0.96	0.03	0.87-0.99	9.0	Veazie Dam

Table A.4.-Average, reach-specific, estuary and bay survival estimates $(\hat{S}_i)$ of Atlantic salmon smolts acoustically tagged in the Penobscot and Piscataquis Rivers in 2011.

Parameter	$\hat{S}_i$	*SE*	95% CI	Reach Length (km)	Reach type
S_{16}	0.99	0.01	0.96-1.00	2.5	Estuary
S_{17}	1.00	0.00	1.00-1.00	1.9	Estuary
S_{18}	1.00	0.00	1.00-1.00	0.7	Estuary
S_{19}	1.00	0.00	0.77-1.00	1.2	Estuary
S_{20}	0.98	0.01	0.96-1.00	2.3	Estuary
S_{21}	0.99	0.01	0.95-1.00	2.5	Estuary
S_{22}	1.00	0.00	1.00-1.00	1.7	Estuary
S_{23}	0.99	0.01	0.98-1.00	3.5	Estuary
S_{24}	0.98	0.02	0.91-1.00	0.7	Estuary
S_{25}	1.00	0.00	1.00-1.00	1.3	Estuary
S_{26}	1.00	0.00	1.00-1.00	1.5	Estuary
S_{27}	0.98	0.02	0.90-1.00	1.7	Estuary
S_{28}	1.00	0.00	1.00-1.00	1.5	Estuary
S_{29}	0.99	0.01	0.97-1.00	2.0	Estuary
S_{30}	0.99	0.01	0.93-1.00	1.6	Estuary
S_{31}	0.99	0.01	0.98-1.00	1.2	Estuary
S_{32}	0.94	0.02	0.91-0.96	0.8	Estuary
S_{33}	0.99	0.01	0.96-1.00	1.0	Estuary
S_{34}	1.00	0.00	1.00-1.00	2.6	Estuary
S_{35}	0.99	0.01	0.93-1.00	4.0	Estuary
S_{36}	0.97	0.02	0.91-0.99	6.2	Bay
S_{37}	0.92	0.04	0.78-0.80	4.0	Bay

Appendix B: Cumulative survival probabilities, including release mortality, for acoustically tagged Atlantic salmon smolts released in the Penobscot and Piscataquis Rivers in 2010 and 2011.

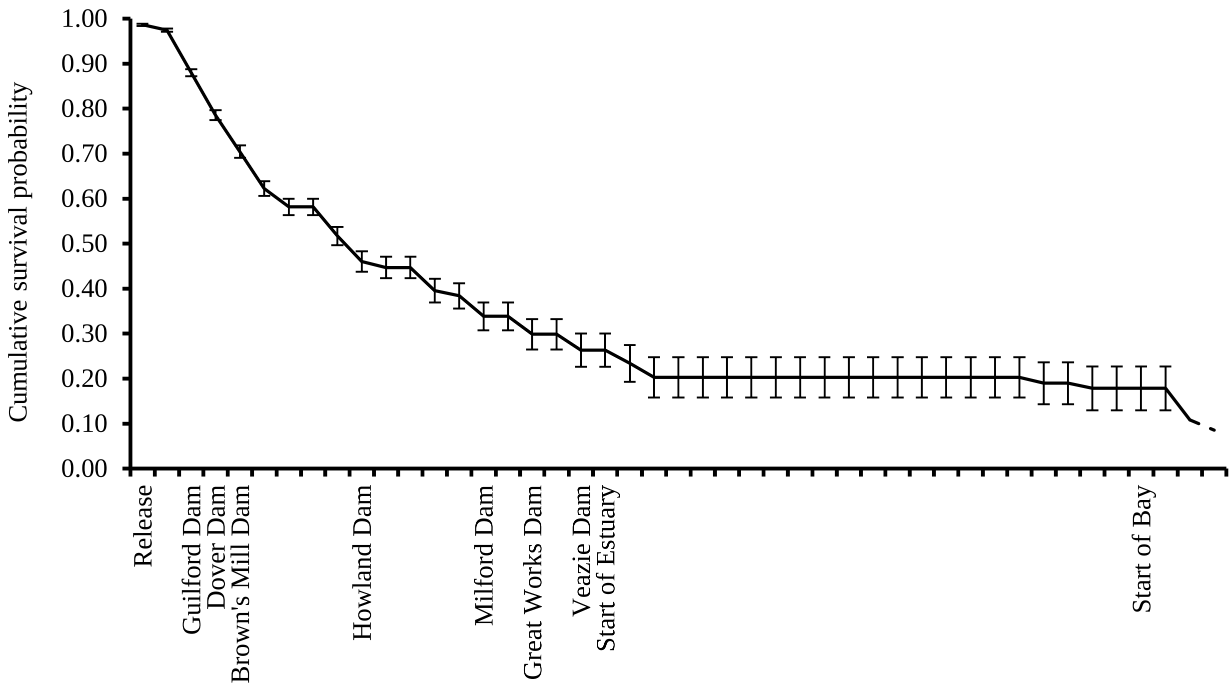

Figure B.1.- Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2010.

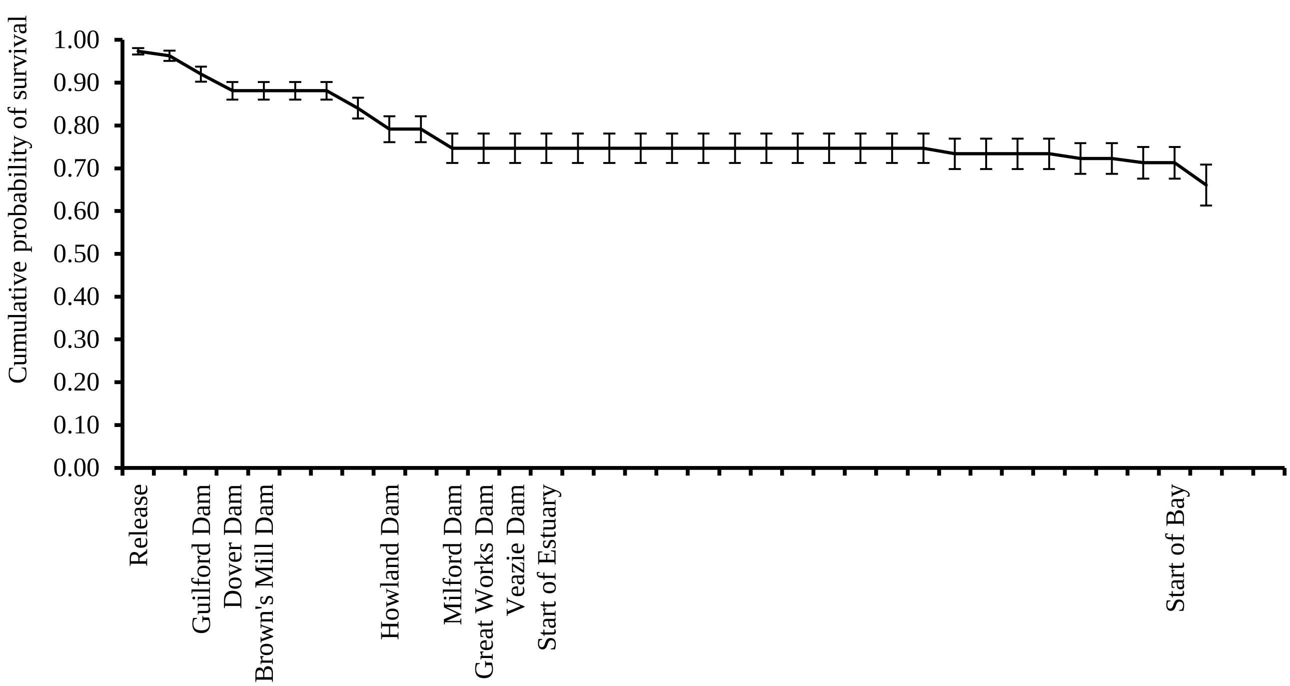

Figure B.2.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2011.

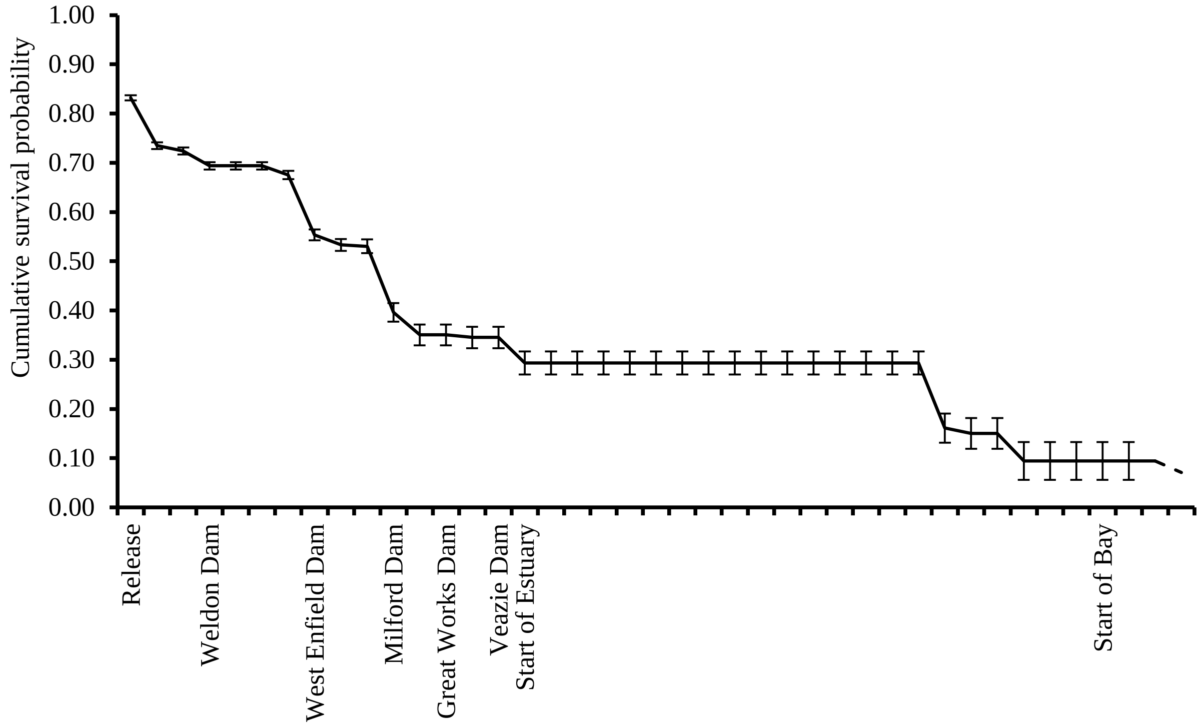

Figure B.3.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released above in the East Branch of the Penobscot River at the Town of Medway, upstream of Weldon Dam in 2010.

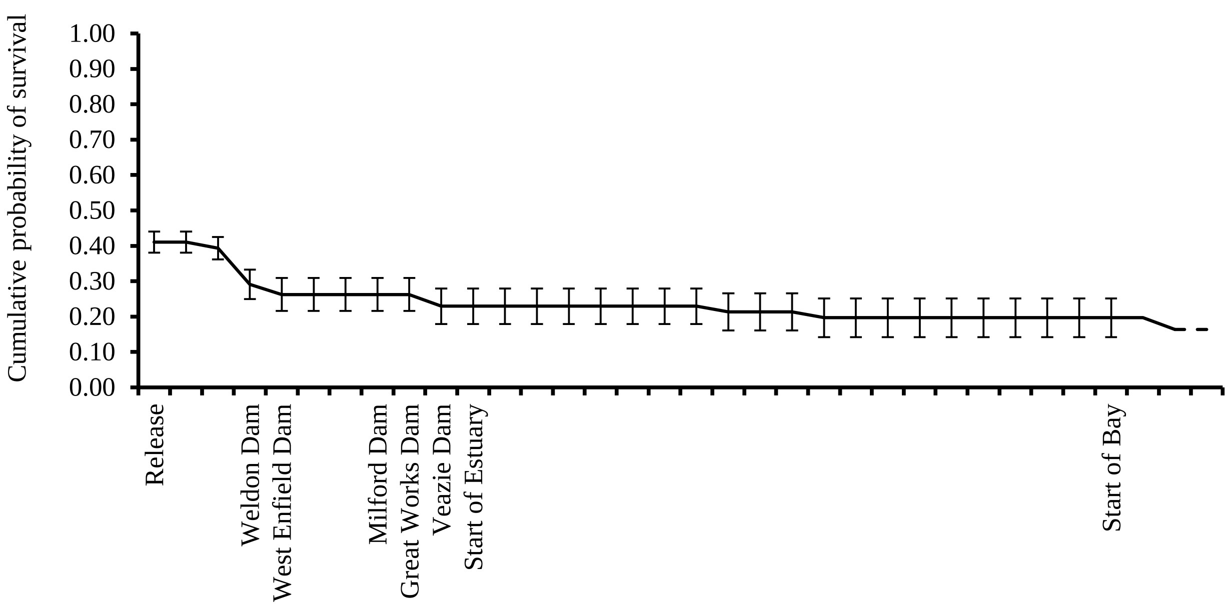

Figure B.4.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released above Weldon Dam in the East Branch of the Penobscot River at the Town of Medway, 2011.

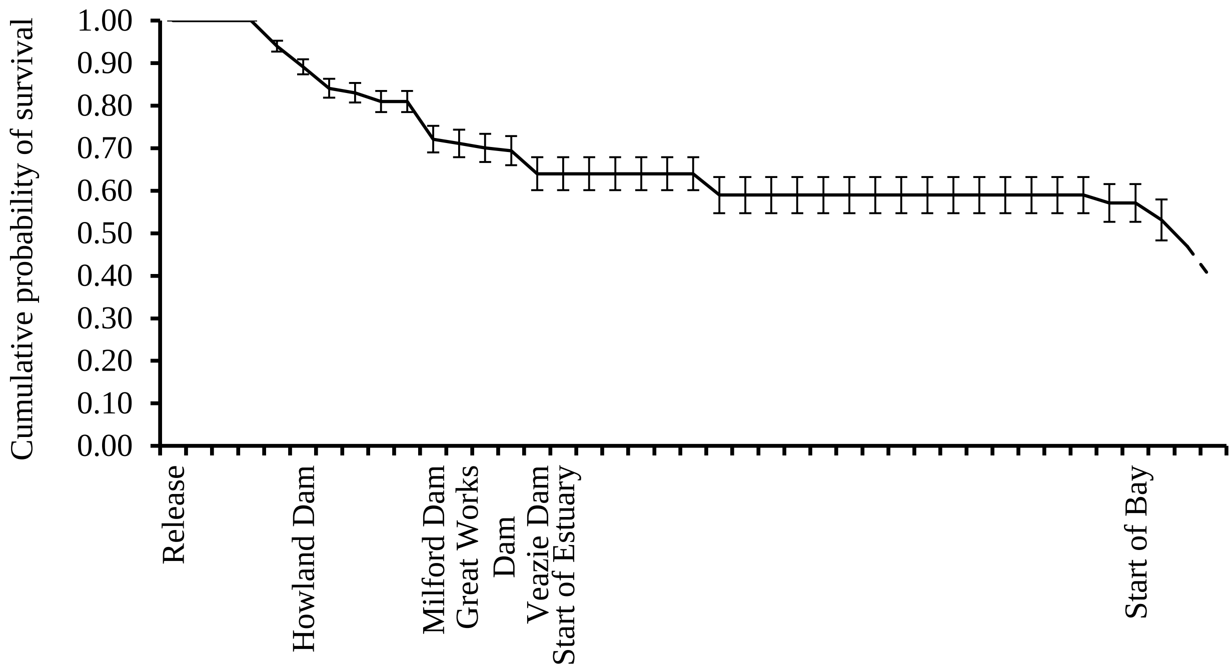

Figure B.5.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2010.

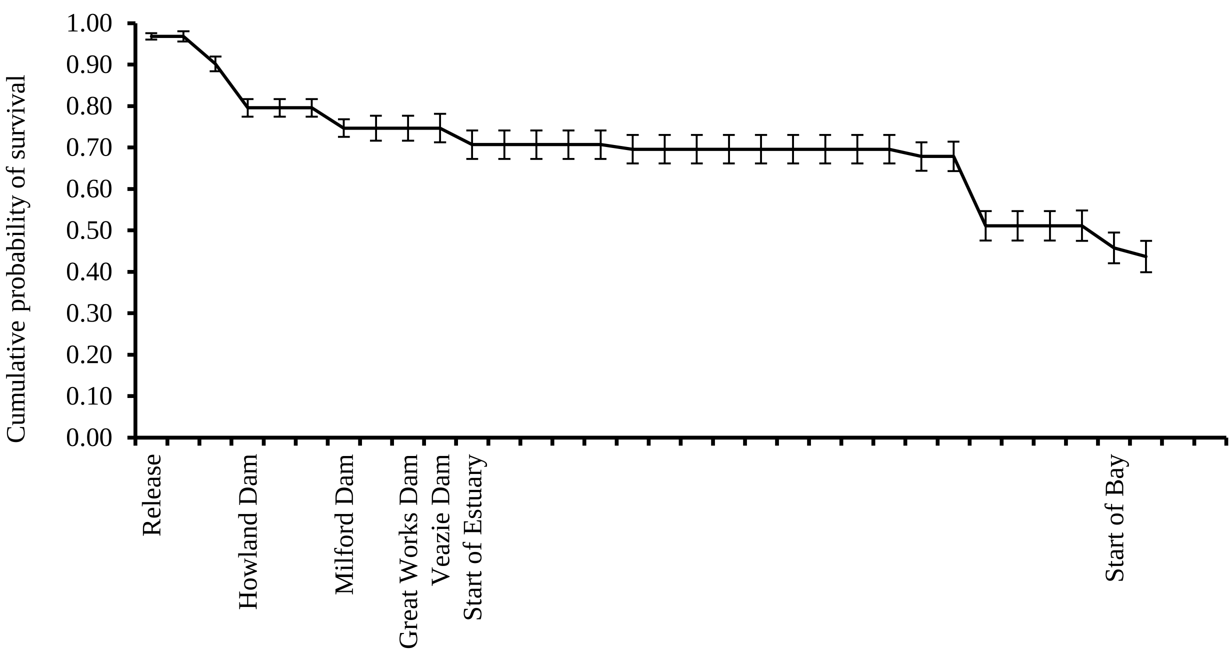

Figure B.6.- Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2011.

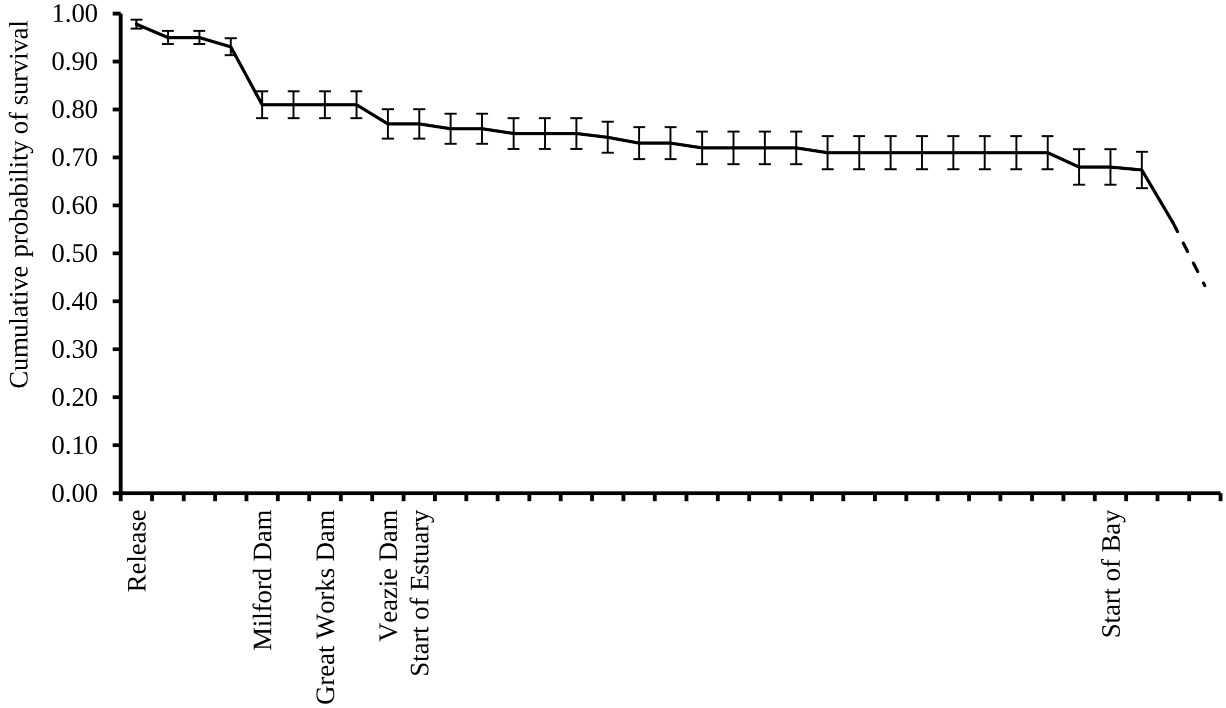

Figure B.7.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released at the mouth of the Passadumkeag River in 2010.

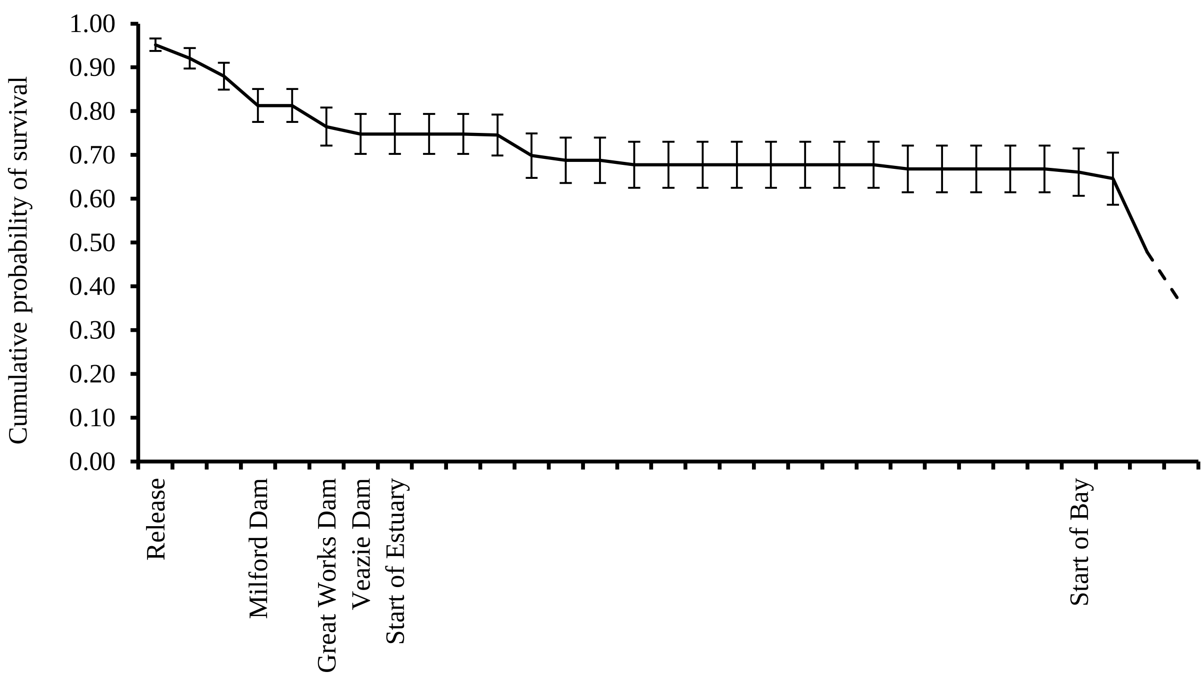

Figure B.8.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released at the mouth of the Passadumkeag River in 2011.

Appendix C: Reach-specific survival estimates and cumulative survival estimates, including release, by release group of acoustically tagged Atlantic salmon smolts released in the Penobscot and Piscataquis Rivers 2010- 2011.

Table C.1.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2010.

Parameter	S_i	SE	Cumulative S	Delta SE	Reach Type
S_R	0.99	0.03	0.99	0.00	Release
S_{2B}	0.99	0.17	0.97	0.00	No dam
S_{3B}	0.90	0.12	0.88	0.01	No dam
S_{4B}	0.89	0.13	0.79	0.01	Dover Dam
S_{5B}	0.90	0.14	0.70	0.01	Brown's Mill Dam
S_{6B}	0.88	0.15	0.62	0.02	No dam
S_{7B}	0.93	0.16	0.58	0.02	No dam
S_{8B}	1.00	0.16	0.58	0.02	No dam
S_{9B}	0.89	0.15	0.52	0.02	No dam
S_{10B}	0.89	0.17	0.46	0.02	Howland Dam
S_{11}	0.97	0.18	0.45	0.02	No dam
S_{12}	1.00	0.18	0.45	0.02	No dam
S_{13}	0.89	0.17	0.40	0.03	No dam
S_{14}	0.97	0.19	0.38	0.03	No dam
S_{15}	0.88	0.19	0.34	0.03	Milford Dam
S_{16}	1.00	0.21	0.34	0.03	No dam
S_{17}	0.88	0.20	0.30	0.03	Great Works Dam
S_{18}	1.00	0.22	0.30	0.03	No dam
S_{19}	0.88	0.22	0.26	0.04	Veazie Dam
S_{20}	1.00	0.22	0.26	0.04	Start of Estuary
S_{21}	0.89	0.23	0.23	0.04	Estuary
S_{22}	0.87	0.25	0.20	0.04	Estuary
S_{23}	1.00	0.28	0.20	0.04	Estuary
S_{24}	1.00	0.26	0.20	0.04	Estuary
S_{25}	1.00	0.26	0.20	0.04	Estuary
S_{26}	1.00	0.26	0.20	0.04	Estuary
S_{27}	1.00	0.26	0.20	0.04	Estuary
S_{28}	1.00	0.37	0.20	0.04	Estuary
S_{29}	1.00	0.37	0.20	0.04	Estuary
S_{30}	1.00	0.26	0.20	0.04	Estuary
S_{31}	1.00	0.26	0.20	0.04	Estuary
S_{32}	1.00	0.26	0.20	0.04	Estuary
S_{33}	1.00	0.26	0.20	0.04	Estuary
S_{34}	1.00	0.26	0.20	0.04	Estuary
S_{35}	1.00	0.26	0.20	0.04	Estuary
S_{36}	1.00	0.26	0.20	0.04	Estuary
S_{37}	1.00	0.26	0.20	0.04	Estuary
S_{38}	0.94	0.26	0.19	0.05	Estuary
S_{39}	1.00	0.27	0.19	0.05	Estuary
S_{40}	0.94	0.27	0.18	0.05	Estuary
S_{41}	1.00	0.28	0.18	0.05	Estuary
S_{42}	1.00	0.27	0.18	0.05	Bay
S_{43}	1.00	0.28	0.18	0.05	Bay

Table C.2.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2011.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	0.97	0.02	0.97	0.01	Release
S_{2B}	0.99	0.02	0.96	0.01	No Dam
S_{3B}	0.96	0.03	0.92	0.02	No Dam
S_{4B}	0.96	0.02	0.88	0.02	Dover Dam
S_{5B}	1.00	0.00	0.88	0.02	Brown's Mill Dam
S_{6B}	1.00	0.00	0.88	0.02	No Dam
S_{7B}	1.00	0.00	0.88	0.02	No Dam
S_{8B}	0.95	0.03	0.84	0.02	No Dam
S_{9B}	0.94	0.04	0.79	0.03	Howland Dam
S_{10}	1.00	0.00	0.79	0.03	No Dam
S_{11}					No Dam
S_{12}	0.94	0.04	0.75	0.03	Milford Dam
S_{13}					No Dam
S_{14}	1.00	0.00	0.75	0.03	Great Works Dam
S_{15}	1.00	0.00	0.75	0.03	Veazie Dam
S_{16}	1.00	0.00	0.75	0.03	Estuary
S_{17}	1.00	0.00	0.75	0.03	Estuary
S_{18}	1.00	0.00	0.75	0.03	Estuary
S_{19}	1.00	0.00	0.75	0.03	Estuary
S_{20}	1.00	0.00	0.75	0.03	Estuary
S_{21}	1.00	0.00	0.75	0.03	Estuary
S_{22}	1.00	0.00	0.75	0.03	Estuary
S_{23}	1.00	0.00	0.75	0.03	Estuary
S_{24}	1.00	0.00	0.75	0.03	Estuary
S_{25}	1.00	0.00	0.75	0.03	Estuary
S_{26}	1.00	0.00	0.75	0.03	Estuary
S_{27}	1.00	0.00	0.75	0.03	Estuary
S_{28}	1.00	0.00	0.75	0.03	Estuary
S_{29}	0.98	0.02	0.73	0.04	Estuary
S_{30}	1.00	0.00	0.73	0.04	Estuary
S_{31}	1.00	0.00	0.73	0.04	Estuary
S_{32}	1.00	0.00	0.73	0.04	Estuary
S_{33}	0.99	0.02	0.72	0.04	Estuary
S_{34}	1.00	0.00	0.72	0.04	Estuary
S_{35}	0.99	0.02	0.71	0.04	Estuary
S_{36}	1.00	0.00	0.71	0.04	Bay
S_{37}	0.93	0.07	0.66	0.05	Bay

Table C.3.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Penobscot River at the Town of Medway in 2011.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	0.41	0.06	0.41	0.03	Release
S_{2A}	1.00	0.00	0.41	0.03	No Dam
S_{3A}	0.96	0.04	0.39	0.03	No Dam
S_{4A}	0.74	0.10	0.29	0.04	Weldon Dam
$S_{5A...9A}$	0.90	0.09	0.26	0.05	West Enfield Dam
S_{10}	1.00	0.00	0.26	0.05	No Dam
S_{11}	1.00	0.00	0.26	0.05	No Dam
S_{12}	1.00	0.00	0.26	0.05	Milford Dam
S_{13}					No Dam
S_{14}	1.00	0.00	0.26	0.05	Great Works Dam
S_{15}	0.87	0.08	0.23	0.05	Veazie Dam
S_{16}	1.00	0.00	0.23	0.05	Estuary
S_{17}	1.00	0.00	0.23	0.05	Estuary
S_{18}	1.00	0.00	0.23	0.05	Estuary
S_{19}	1.00	0.00	0.23	0.05	Estuary
S_{20}	1.00	0.00	0.23	0.05	Estuary
S_{21}	1.00	0.00	0.23	0.05	Estuary
S_{22}	1.00	0.00	0.23	0.05	Estuary
S_{23}	1.00	0.00	0.23	0.05	Estuary
S_{24}	0.93	0.07	0.21	0.05	Estuary
S_{25}	1.00	0.00	0.21	0.05	Estuary
S_{26}	1.00	0.00	0.21	0.05	Estuary
S_{27}	0.92	0.07	0.20	0.05	Estuary
S_{28}	1.00	0.00	0.20	0.05	Estuary
S_{29}	1.00	0.00	0.20	0.05	Estuary
S_{30}	1.00	0.00	0.20	0.05	Estuary
S_{31}	1.00	0.00	0.20	0.05	Estuary
S_{32}	1.00	0.00	0.20	0.05	Estuary
S_{33}	1.00	0.00	0.20	0.05	Estuary
S_{34}	1.00	0.00	0.20	0.05	Estuary
S_{35}	1.00	0.00	0.20	0.05	Estuary
S_{36}	1.00	0.00	0.20	0.05	Bay
S_{37}	1.00	0.00	0.20	0.05	Bay

Table C.4.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Penobscot River at the Town of Medway in 2011.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	0.41	0.06	0.41	0.03	Release
S_{2A}	1.00	0.00	0.41	0.03	No Dam
S_{3A}	0.96	0.04	0.39	0.04	No Dam
S_{4A}	0.74	0.10	0.29	0.08	Weldon Dam
$S_{5A...9A}$	0.90	0.09	0.26	0.11	West Enfield Dam
S_{10}	1.00	0.00	0.26	0.11	No Dam
S_{11}	1.00	0.00	0.26	0.11	No Dam
S_{12}	1.00	0.00	0.26	0.11	Milford Dam
S_{13}					No Dam
S_{14}	1.00	0.00	0.26	0.11	Great Works Dam
S_{15}	0.87	0.08	0.23	0.13	Veazie Dam
S_{16}	1.00	0.00	0.23	0.13	Estuary
S_{17}	1.00	0.00	0.23	0.13	Estuary
S_{18}	1.00	0.00	0.23	0.13	Estuary
S_{19}	1.00	0.00	0.23	0.13	Estuary
S_{20}	1.00	0.00	0.23	0.13	Estuary
S_{21}	1.00	0.00	0.23	0.13	Estuary
S_{22}	1.00	0.00	0.23	0.13	Estuary
S_{23}	1.00	0.00	0.23	0.13	Estuary
S_{24}	0.93	0.07	0.21	0.14	Estuary
S_{25}	1.00	0.00	0.21	0.14	Estuary
S_{26}	1.00	0.00	0.21	0.14	Estuary
S_{27}	0.92	0.07	0.20	0.16	Estuary
S_{28}	1.00	0.00	0.20	0.16	Estuary
S_{29}	1.00	0.00	0.20	0.16	Estuary
S_{30}	1.00	0.00	0.20	0.16	Estuary
S_{31}	1.00	0.00	0.20	0.16	Estuary
S_{32}	1.00	0.00	0.20	0.16	Estuary
S_{33}	1.00	0.00	0.20	0.16	Estuary
S_{34}	1.00	0.00	0.20	0.16	Estuary
S_{35}	1.00	0.00	0.20	0.16	Estuary
S_{36}	1.00	0.00	0.20	0.16	Bay
S_{37}	1.00	0.00	0.20	0.16	Bay

Table C.5.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2010.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	1.00	0.00	1.00	0.00	Release
$S_{2B \cdots 7B}$	1.00	0.00	1.00	0.00	No dam
S_{8B}	1.00	0.00	1.00	0.00	No dam
S_{9B}	0.94	0.02	0.94	0.01	No dam
S_{10B}	0.95	0.02	0.89	0.02	Howland Dam
S_{11}	0.94	0.03	0.84	0.02	No dam
S_{12}	0.99	0.01	0.83	0.02	No dam
S_{13}	0.98	0.02	0.81	0.02	No dam
S_{14}	1.00	0.00	0.81	0.02	No dam
S_{15}	0.89	0.04	0.72	0.03	Milford Dam
S_{16}	0.99	0.02	0.71	0.03	No dam
S_{17}	0.98	0.02	0.70	0.03	Great Works Dam
S_{18}	0.99	0.02	0.69	0.03	No dam
S_{19}	0.92	0.03	0.64	0.04	Veazie Dam
S_{20}	1.00	0.00	0.64	0.04	Start of Estuary
S_{21}	1.00	0.00	0.64	0.04	Estuary
S_{22}	1.00	0.00	0.64	0.04	Estuary
S_{23}	1.00	0.00	0.64	0.04	Estuary
S_{24}	1.00	0.00	0.64	0.04	Estuary
S_{25}	1.00	0.00	0.64	0.04	Estuary
S_{26}	0.92	0.03	0.59	0.04	Estuary
S_{27}	1.00	0.00	0.59	0.04	Estuary
S_{28}	1.00	0.00	0.59	0.04	Estuary
S_{29}	1.00	0.00	0.59	0.04	Estuary
S_{30}	1.00	0.00	0.59	0.04	Estuary
S_{31}	1.00	0.00	0.59	0.04	Estuary
S_{32}	1.00	0.00	0.59	0.04	Estuary
S_{33}	1.00	0.00	0.59	0.04	Estuary
S_{34}	1.00	0.00	0.59	0.04	Estuary
S_{35}	1.00	0.00	0.59	0.04	Estuary
S_{36}	1.00	0.00	0.59	0.04	Estuary
S_{37}	1.00	0.00	0.59	0.04	Estuary
S_{38}	1.00	0.00	0.59	0.04	Estuary
S_{39}	1.00	0.00	0.59	0.04	Estuary
S_{40}	1.00	0.00	0.59	0.04	Estuary
S_{41}	0.97	0.02	0.57	0.04	Estuary
S_{42}	1.00	0.00	0.57	0.04	Bay
S_{43}	0.93	0.03	0.53	0.05	Bay

Table C.6.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2011.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	0.97	0.02	0.41	0.01	Release
S_{7B}	1.00	0.00	0.41	0.01	No Dam
S_{8B}	0.93	0.03	0.39	0.02	No Dam
S_{9B}	0.88	0.04	0.29	0.02	Howland Dam
S_{10}	1.00	0.00	0.26	0.02	No Dam
S_{11}	1.00	0.00	0.26	0.02	No Dam
S_{12}	0.94	0.03	0.26	0.02	Milford Dam
S_{13}	1.00	0.00	0.26	0.03	No Dam
S_{14}	1.00	0.00	0.26	0.03	Great Works Dam
S_{15}	1.00	0.00	0.23	0.03	Veazie Dam
S_{16}	0.95	0.03	0.23	0.03	Estuary
S_{17}	1.00	0.00	0.23	0.03	Estuary
S_{18}	1.00	0.00	0.23	0.03	Estuary
S_{19}	1.00	0.00	0.23	0.03	Estuary
S_{20}	1.00	0.00	0.23	0.03	Estuary
S_{21}	0.98	0.02	0.23	0.03	Estuary
S_{22}	1.00	0.00	0.23	0.03	Estuary
S_{23}	1.00	0.00	0.23	0.03	Estuary
S_{24}	1.00	0.00	0.21	0.03	Estuary
S_{25}	1.00	0.00	0.21	0.03	Estuary
S_{26}	1.00	0.00	0.21	0.03	Estuary
S_{27}	1.00	0.00	0.20	0.03	Estuary
S_{28}	1.00	0.00	0.20	0.03	Estuary
S_{29}	1.00	0.00	0.20	0.03	Estuary
S_{30}	0.98	0.03	0.20	0.03	Estuary
S_{31}	1.00	0.00	0.20	0.04	Estuary
S_{32}	0.75	0.06	0.20	0.04	Estuary
S_{33}	1.00	0.00	0.20	0.04	Estuary
S_{34}	1.00	0.00	0.20	0.04	Estuary
S_{35}	1.00	0.00	0.20	0.04	Estuary
S_{36}	0.90	0.05	0.20	0.04	Bay
S_{37}	0.95	0.03	0.20	0.04	Bay

Table C.7.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the mouth of the Passadumkeag River 2010.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	0.98	0.02	0.98	0.01	Release
$S_{1\ldots12}$	0.97	0.02	0.95	0.01	No dam
S_{13}	1.00	0.00	0.95	0.01	No dam
S_{14}	0.98	0.02	0.93	0.02	No dam
S_{15}	0.87	0.04	0.81	0.03	Milford Dam
S_{16}	1.00	0.00	0.81	0.03	No dam
S_{17}	1.00	0.00	0.81	0.03	Great Works Dam
S_{18}	1.00	0.00	0.81	0.03	No dam
S_{19}	0.95	0.02	0.77	0.03	Veazie Dam
S_{20}	1.00	0.00	0.77	0.03	Start of Estuary
S_{21}	0.99	0.01	0.76	0.03	Estuary
S_{22}	1.00	0.00	0.76	0.03	Estuary
S_{23}	0.99	0.01	0.75	0.03	Estuary
S_{24}	1.00	0.00	0.75	0.03	Estuary
S_{25}	1.00	0.00	0.75	0.03	Estuary
S_{26}	0.99	0.01	0.74	0.03	Estuary
S_{27}	0.98	0.02	0.73	0.03	Estuary
S_{28}	1.00	0.00	0.73	0.03	Estuary
S_{29}	0.99	0.01	0.72	0.03	Estuary
S_{30}	1.00	0.00	0.72	0.03	Estuary
S_{31}	1.00	0.00	0.72	0.03	Estuary
S_{32}	1.00	0.00	0.72	0.03	Estuary
S_{33}	0.99	0.01	0.71	0.03	Estuary
S_{34}	1.00	0.00	0.71	0.03	Estuary
S_{35}	1.00	0.00	0.71	0.03	Estuary
S_{36}	1.00	0.00	0.71	0.03	Estuary
S_{37}	1.00	0.00	0.71	0.03	Estuary
S_{38}	1.00	0.00	0.71	0.03	Estuary
S_{39}	1.00	0.00	0.71	0.03	Estuary
S_{40}	1.00	0.00	0.71	0.03	Estuary
S_{41}	0.96	0.02	0.68	0.04	Estuary
S_{42}	1.00	0.00	0.68	0.04	Bay
S_{43}	0.99	0.02	0.67	0.04	Bay

Table C.8.- Reach-specific survival rates and (S_i) cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the mouth of the Passadumkeag River, 2011.

Parameter	Si	SE	Cumulative S	Delta SE	Reach Type
S_R	0.95	0.02	0.95	0.01	Release
$S_{1\ldots10}$	0.97	0.03	0.92	0.02	No Dam
S_{11}	0.96	0.03	0.88	0.03	No Dam
S_{12}	0.92	0.03	0.81	0.04	Milford Dam
S_{13}	1.00	0.00	0.81	0.04	No Dam
S_{14}	0.94	0.03	0.76	0.04	Great Works Dam
S_{15}	0.98	0.02	0.75	0.05	Veazie Dam
S_{16}	1.00	0.00	0.75	0.05	Estuary
S_{17}	1.00	0.00	0.75	0.05	Estuary
S_{18}	1.00	0.00	0.75	0.05	Estuary
S_{19}	1.00	0.01	0.75	0.05	Estuary
S_{20}	0.94	0.03	0.70	0.05	Estuary
S_{21}	0.98	0.02	0.69	0.05	Estuary
S_{22}	1.00	0.00	0.69	0.05	Estuary
S_{23}	0.99	0.01	0.68	0.05	Estuary
S_{24}	1.00	0.00	0.68	0.05	Estuary
S_{25}	1.00	0.00	0.68	0.05	Estuary
S_{26}	1.00	0.00	0.68	0.05	Estuary
S_{27}	1.00	0.00	0.68	0.05	Estuary
S_{28}	1.00	0.00	0.68	0.05	Estuary
S_{29}	1.00	0.00	0.68	0.05	Estuary
S_{30}	1.00	0.00	0.68	0.05	Estuary
S_{31}	0.99	0.01	0.67	0.05	Estuary
S_{32}	1.00	0.00	0.67	0.05	Estuary
S_{33}	1.00	0.00	0.67	0.05	Estuary
S_{34}	1.00	0.00	0.67	0.05	Estuary
S_{35}	1.00	0.00	0.67	0.05	Estuary
S_{36}	0.99	0.02	0.66	0.05	Bay
S_{37}	0.98	0.04	0.65	0.06	Bay

Appendix D: Cumulative survival probabilities, excluding release mortality, for acoustically tagged Atlantic salmon smolts released in the Penobscot and Piscataquis Rivers in 2010 and 2011.

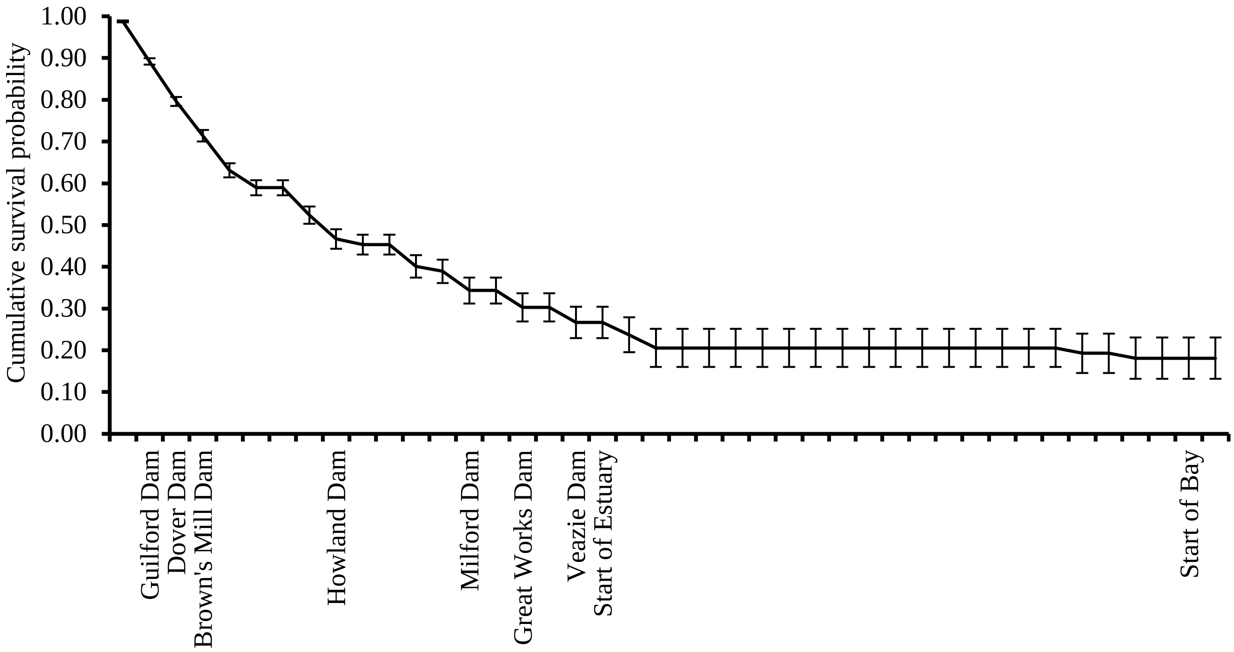

Figure D.1.- Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2010.

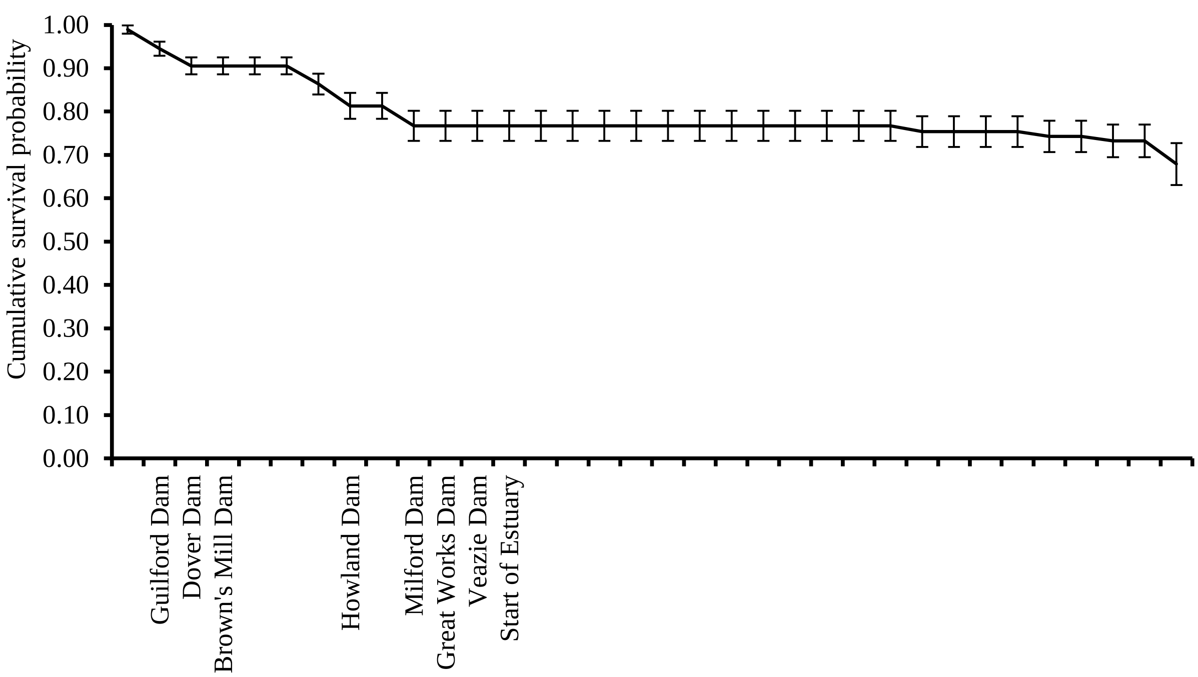

Figure D.2.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2011.

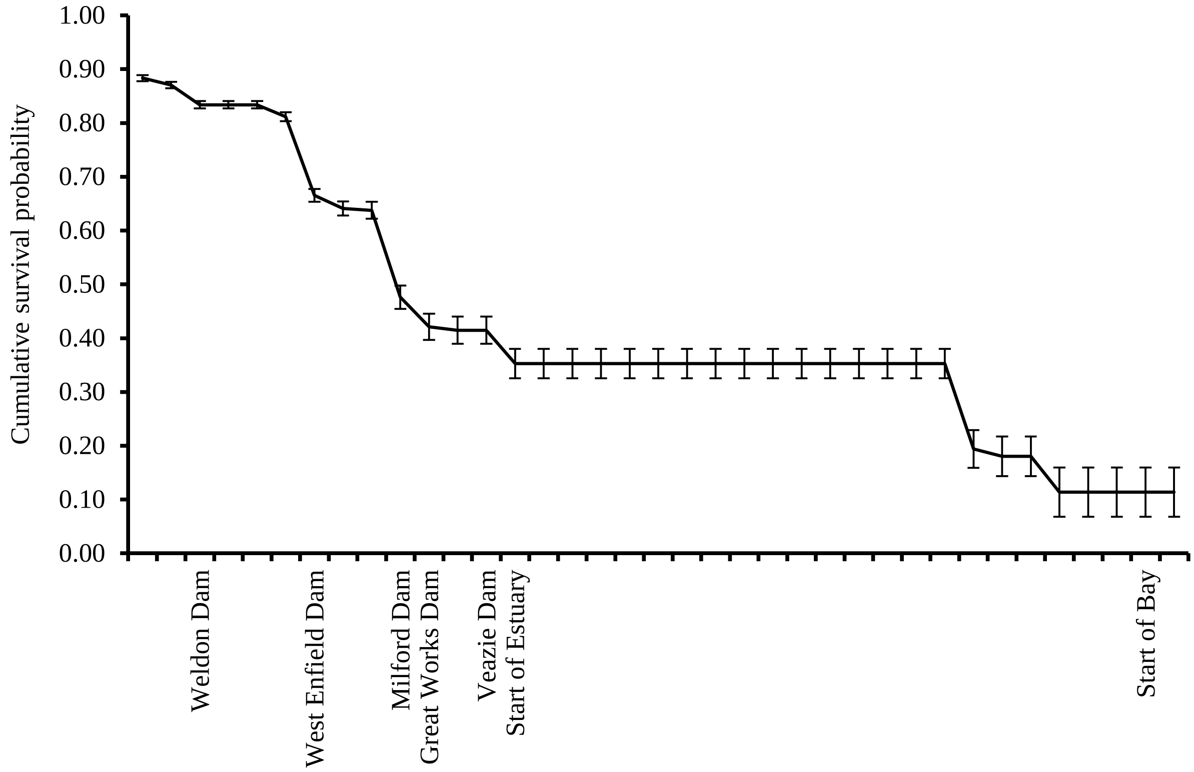

Figure D.3.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released above in the East Branch of the Penobscot River at the Town of Medway, upstream of Weldon Dam in 2010.

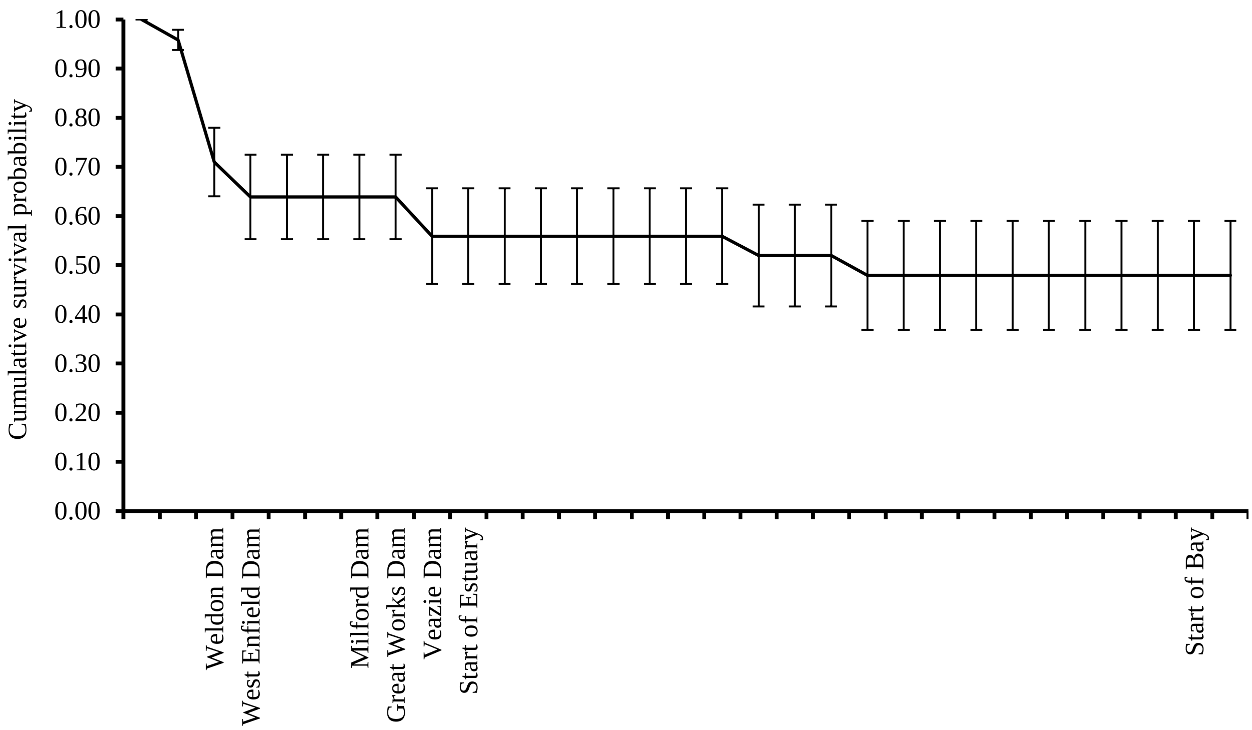

Figure D.4.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released above Weldon Dam in the East Branch of the Penobscot River at the Town of Medway, 2010.

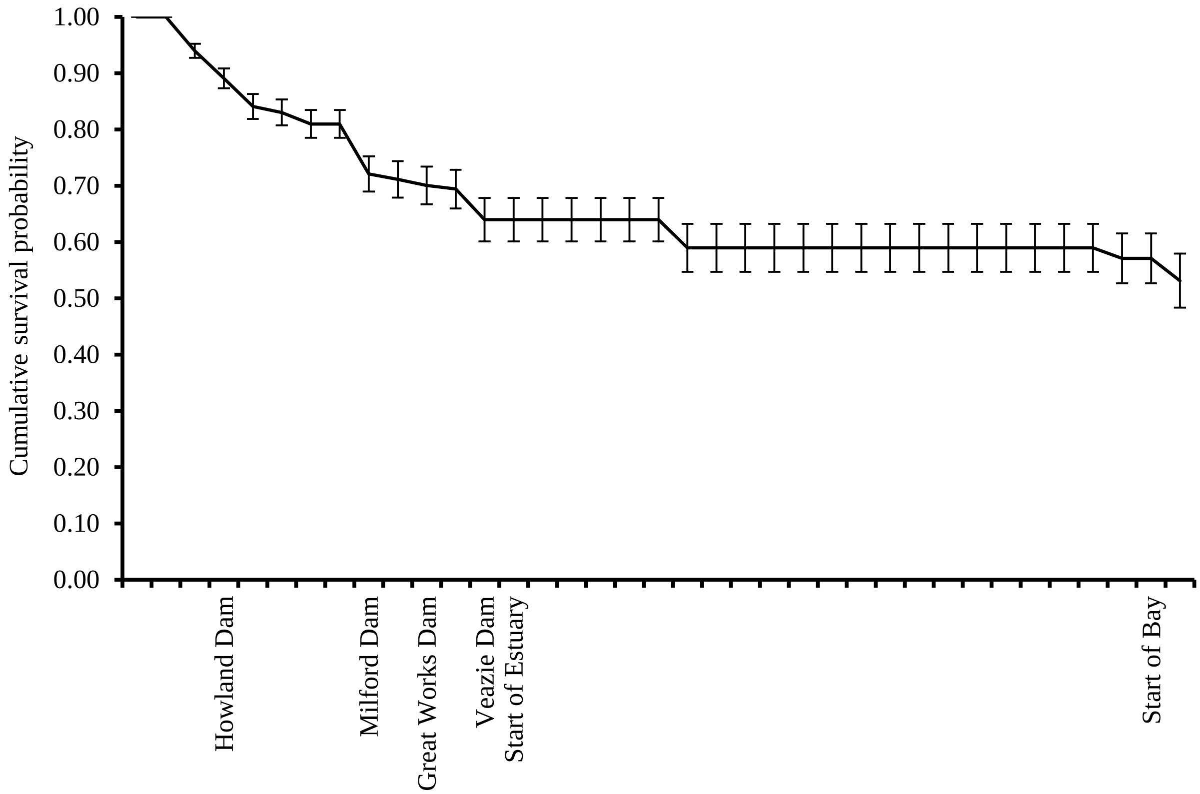

Figure D.5.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2010.

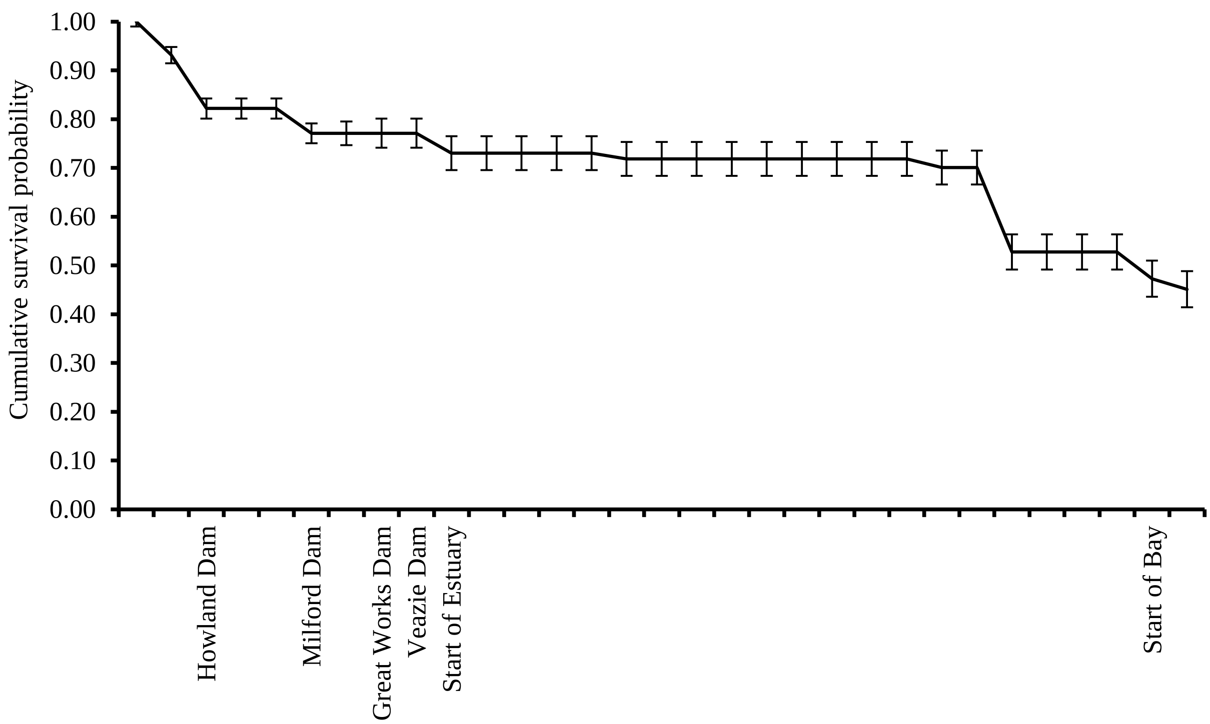

Figure D.6.- Cumulative survival probabilities (±SE) of Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2011.

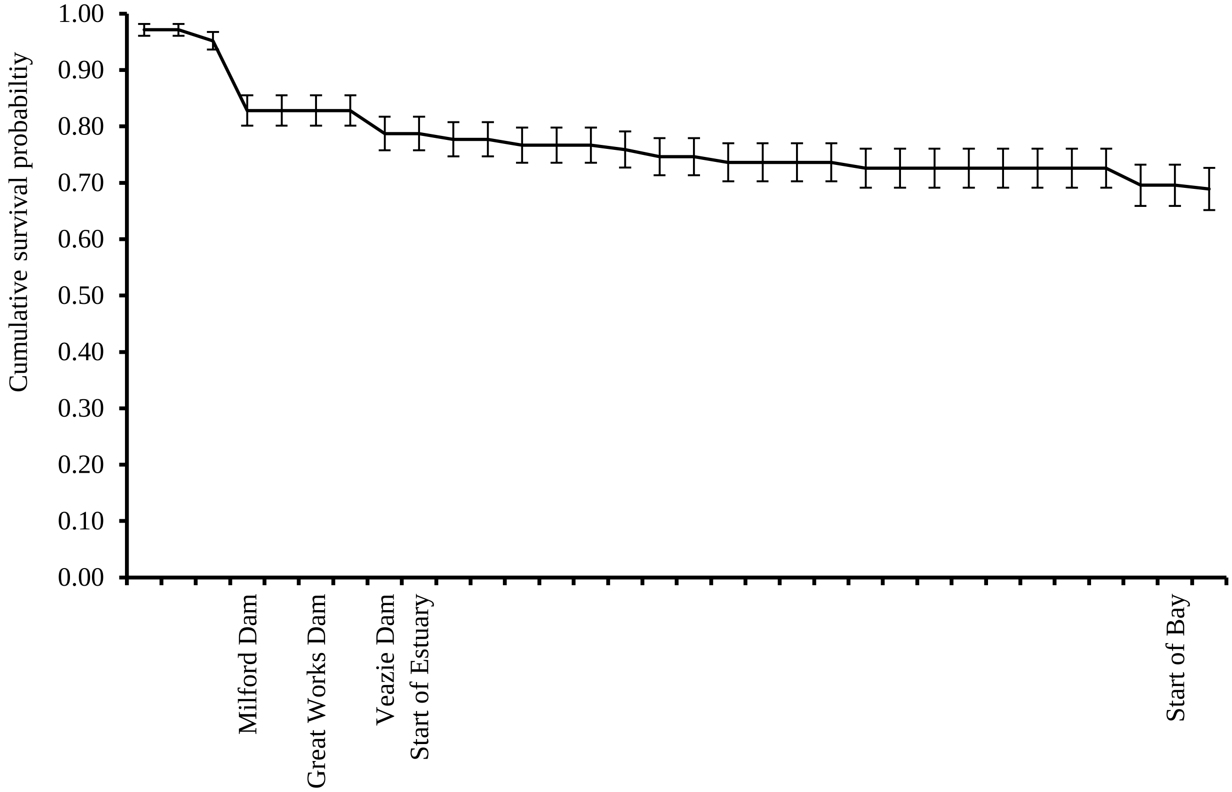

Figure D.7.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released at the mouth of the Passadumkeag River in 2010.

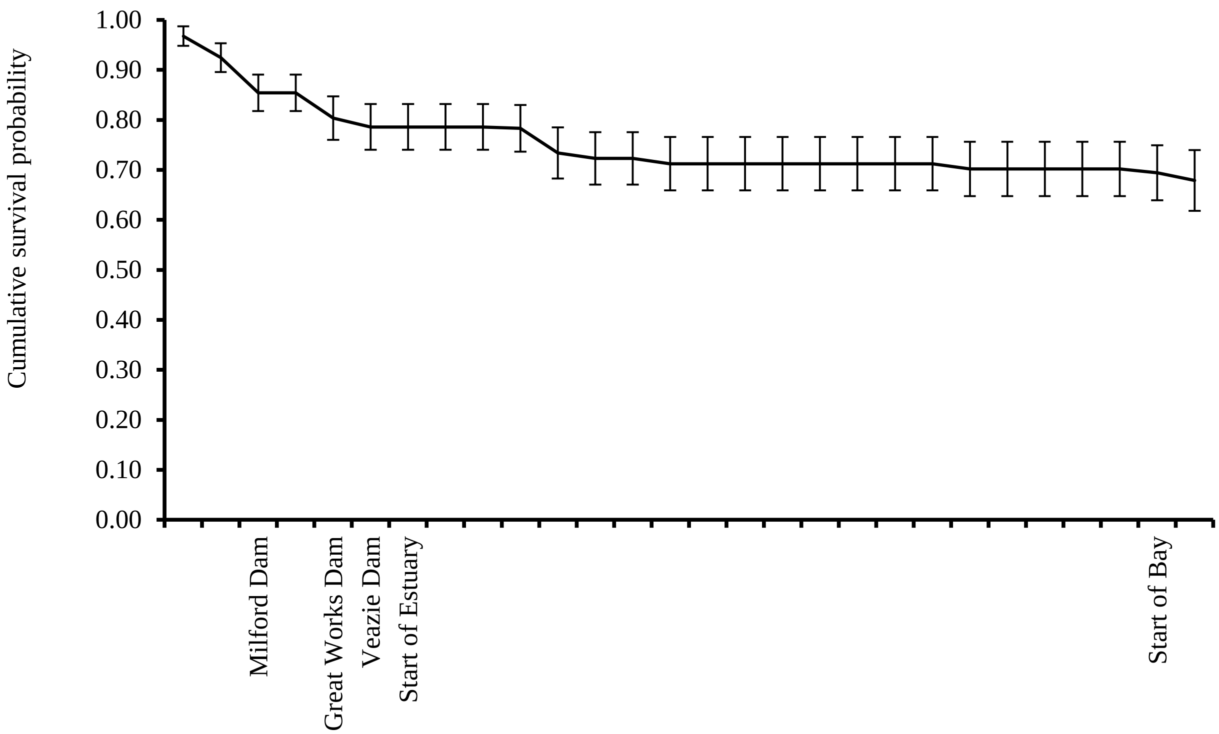

Figure D.8.-Cumulative survival probabilities (±SE) of Atlantic salmon smolts released at the mouth of the Passadumkeag River in 2011.

Appendix E: Reach-specific survival estimates and cumulative survival estimates, excluding release, by release group of acoustically tagged Atlantic salmon smolts released in the Penobscot and Piscataquis Rivers 2010- 2011.

Table E.1.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2010.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
S_{2B}	0.99	0.17	0.99	0.00	No dam
S_{3B}	0.90	0.12	0.89	0.01	Guilford Dam
S_{4B}	0.89	0.13	0.80	0.01	Dover Dam
S_{5B}	0.90	0.14	0.71	0.01	Brown's Mill Dam
S_{6B}	0.88	0.15	0.63	0.02	No dam
S_{7B}	0.93	0.16	0.59	0.02	No dam
S_{8B}	1.00	0.16	0.59	0.02	No dam
S_{9B}	0.89	0.15	0.52	0.02	No dam
S_{10B}	0.89	0.17	0.47	0.02	Howland Dam
S_{11}	0.97	0.18	0.45	0.02	No dam
S_{12}	1.00	0.18	0.45	0.02	No dam
S_{13}	0.89	0.17	0.40	0.03	No dam
S_{14}	0.97	0.19	0.39	0.03	No dam
S_{15}	0.88	0.19	0.34	0.03	Milford Dam
S_{16}	1.00	0.21	0.34	0.03	No dam
S_{17}	0.88	0.20	0.30	0.03	Great Works Dam
S_{18}	1.00	0.22	0.30	0.03	No dam
S_{19}	0.88	0.22	0.27	0.04	Veazie Dam
S_{20}	1.00	0.22	0.27	0.04	Start of Estuary
S_{21}	0.89	0.23	0.24	0.04	Estuary
S_{22}	0.87	0.25	0.21	0.05	Estuary
S_{23}	1.00	0.28	0.21	0.05	Estuary
S_{24}	1.00	0.26	0.21	0.05	Estuary
S_{25}	1.00	0.26	0.21	0.05	Estuary
S_{26}	1.00	0.26	0.21	0.05	Estuary
S_{27}	1.00	0.26	0.21	0.05	Estuary
S_{28}	1.00	0.37	0.21	0.05	Estuary
S_{29}	1.00	0.37	0.21	0.05	Estuary
S_{30}	1.00	0.26	0.21	0.05	Estuary
S_{31}	1.00	0.26	0.21	0.05	Estuary
S_{32}	1.00	0.26	0.21	0.05	Estuary
S_{33}	1.00	0.26	0.21	0.05	Estuary
S_{34}	1.00	0.26	0.21	0.05	Estuary
S_{35}	1.00	0.26	0.21	0.05	Estuary
S_{36}	1.00	0.26	0.21	0.05	Estuary
S_{37}	1.00	0.26	0.21	0.05	Estuary
S_{38}	0.94	0.26	0.19	0.05	Estuary
S_{39}	1.00	0.27	0.19	0.05	Estuary
S_{40}	0.94	0.27	0.18	0.05	Estuary
S_{41}	1.00	0.28	0.18	0.05	Estuary
S_{42}	1.00	0.27	0.18	0.05	Bay
S_{43}	1.00	0.28	0.18	0.05	Bay

Table E.2.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Piscataquis River at the Town of Abbot in 2011.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
S_{2B}	0.99	0.02	0.99	0.01	No Dam
S_{3B}	0.96	0.03	0.95	0.02	Guilford Dam
S_{4B}	0.96	0.02	0.91	0.02	Dover Dam
S_{5B}	1.00	0.00	0.91	0.02	Brown's Mill Dam
S_{6B}	1.00	0.00	0.91	0.02	No Dam
S_{7B}	1.00	0.00	0.91	0.02	No Dam
S_{8B}	0.95	0.03	0.86	0.02	No Dam
S_{9B}	0.94	0.04	0.81	0.03	Howland Dam
S_{10}	1.00	0.00	0.81	0.03	No Dam
S_{11}					No Dam
S_{12}	0.94	0.04	0.77	0.03	Milford Dam
S_{13}					No Dam
S_{14}	1.00	0.00	0.77	0.03	Great Works Dam
S_{15}	1.00	0.00	0.77	0.03	Veazie Dam
S_{16}	1.00	0.00	0.77	0.03	Estuary
S_{17}	1.00	0.00	0.77	0.03	Estuary
S_{18}	1.00	0.00	0.77	0.03	Estuary
S_{19}	1.00	0.00	0.77	0.03	Estuary
S_{20}	1.00	0.00	0.77	0.03	Estuary
S_{21}	1.00	0.00	0.77	0.03	Estuary
S_{22}	1.00	0.00	0.77	0.03	Estuary
S_{23}	1.00	0.00	0.77	0.03	Estuary
S_{24}	1.00	0.00	0.77	0.03	Estuary
S_{25}	1.00	0.00	0.77	0.03	Estuary
S_{26}	1.00	0.00	0.77	0.03	Estuary
S_{27}	1.00	0.00	0.77	0.03	Estuary
S_{28}	1.00	0.00	0.77	0.03	Estuary
S_{29}	0.98	0.02	0.75	0.04	Estuary
S_{30}	1.00	0.00	0.75	0.04	Estuary
S_{31}	1.00	0.00	0.75	0.04	Estuary
S_{32}	1.00	0.00	0.75	0.04	Estuary
S_{33}	0.99	0.02	0.74	0.04	Estuary
S_{34}	1.00	0.00	0.74	0.04	Estuary
S_{35}	0.99	0.02	0.73	0.04	Estuary
S_{36}	1.00	0.00	0.73	0.04	Bay
S_{37}	0.93	0.07	0.68	0.05	Bay

Table E.3.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Penobscot River at the Town of Medway in 2010.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
S_{2A}	0.88	0.04	0.88	0.01	No Dam
S_{3A}	0.99	0.02	0.87	0.01	No Dam
S_{4A}	0.96	0.03	0.83	0.01	Weldon Dam
S_{5A}	1.00	0.00	0.83	0.01	No Dam
S_{6A}	1.00	0.00	0.83	0.01	No Dam
S_{7A}	0.97	0.04	0.81	0.01	No Dam
$S_{8A, 9A, 10A}$	0.82	0.06	0.67	0.01	West Enfield Dam
S_{11}					No Dam
S_{12}	0.96	0.05	0.64	0.01	No Dam
S_{13}	0.99	0.08	0.64	0.02	No Dam
S_{14}					No Dam
S_{15}	0.75	0.10	0.48	0.02	Milford Dam
S_{16}					No dam
S_{17}	0.88	0.08	0.42	0.02	Great Works Dam
S_{18}	1.00	0.00	0.41	0.03	No dam
S_{19}	1.00	0.00	0.41	0.03	Veazie Dam
S_{20}	0.85	0.08	0.35	0.03	Start of Estuary
S_{21}	1.00	0.00	0.35	0.03	Estuary
S_{22}	1.00	0.00	0.35	0.03	Estuary
S_{23}	1.00	0.00	0.35	0.03	Estuary
S_{24}	1.00	0.00	0.35	0.03	Estuary
S_{25}	1.00	0.00	0.35	0.03	Estuary
S_{26}	1.00	0.00	0.35	0.03	Estuary
S_{27}	1.00	0.00	0.35	0.03	Estuary
S_{28}	1.00	0.00	0.35	0.03	Estuary
S_{29}	1.00	0.00	0.35	0.03	Estuary
S_{30}	1.00	0.00	0.35	0.03	Estuary
S_{31}	1.00	0.00	0.35	0.03	Estuary
S_{32}	1.00	0.00	0.35	0.03	Estuary
S_{33}	1.00	0.00	0.35	0.03	Estuary
S_{34}	1.00	0.00	0.35	0.03	Estuary
S_{35}	1.00	0.00	0.35	0.03	Estuary
S_{36}	0.55	0.11	0.19	0.04	Estuary
S_{37}	0.93	0.09	0.18	0.04	Estuary
S_{38}	1.00	0.00	0.18	0.04	Estuary
S_{39}	0.63	0.15	0.11	0.05	Estuary
S_{40}	1.00	0.00	0.11	0.05	Estuary
S_{41}	1.00	0.00	0.11	0.05	Estuary
S_{42}	1.00	0.00	0.11	0.05	Bay
S_{43}	1.00	0.00	0.11	0.05	Bay

Table E.4.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, wild Atlantic salmon smolts released in the Penobscot River at the Town of Medway in 2011.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
S_{2A}	1.00	0.00	1.00	0.00	No Dam
S_{3A}	0.96	0.04	0.96	0.02	No Dam
S_{4A}	0.74	0.10	0.71	0.07	Weldon Dam
$S_{5A...9A}$	0.90	0.09	0.64	0.09	West Enfield Dam
S_{10}	1.00	0.00	0.64	0.09	No Dam
S_{11}	1.00	0.00	0.64	0.09	No Dam
S_{12}	1.00	0.00	0.64	0.09	Milford Dam
S_{13}					No Dam
S_{14}	1.00	0.00	0.64	0.09	Great Works Dam
S_{15}	0.87	0.08	0.56	0.10	Veazie Dam
S_{16}	1.00	0.00	0.56	0.10	Estuary
S_{17}	1.00	0.00	0.56	0.10	Estuary
S_{18}	1.00	0.00	0.56	0.10	Estuary
S_{19}	1.00	0.00	0.56	0.10	Estuary
S_{20}	1.00	0.00	0.56	0.10	Estuary
S_{21}	1.00	0.00	0.56	0.10	Estuary
S_{22}	1.00	0.00	0.56	0.10	Estuary
S_{23}	1.00	0.00	0.56	0.10	Estuary
S_{24}	0.93	0.07	0.52	0.10	Estuary
S_{25}	1.00	0.00	0.52	0.10	Estuary
S_{26}	1.00	0.00	0.52	0.10	Estuary
S_{27}	0.92	0.07	0.48	0.11	Estuary
S_{28}	1.00	0.00	0.48	0.11	Estuary
S_{29}	1.00	0.00	0.48	0.11	Estuary
S_{30}	1.00	0.00	0.48	0.11	Estuary
S_{31}	1.00	0.00	0.48	0.11	Estuary
S_{32}	1.00	0.00	0.48	0.11	Estuary
S_{33}	1.00	0.00	0.48	0.11	Estuary
S_{34}	1.00	0.00	0.48	0.11	Estuary
S_{35}	1.00	0.00	0.48	0.11	Estuary
S_{36}	1.00	0.00	0.48	0.11	Bay
S_{37}	1.00	0.00	0.48	0.11	Bay

Table E.5.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2010.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
S_{7B}	1.00	0.00	1.00	0.00	No dam
S_{8B}	1.00	0.00	1.00	0.00	No dam
S_{9B}	0.94	0.02	0.94	0.01	No dam
S_{10B}	0.95	0.02	0.89	0.02	Howland Dam
S_{11}	0.94	0.03	0.84	0.02	No dam
S_{12}	0.99	0.01	0.83	0.02	No dam
S_{13}	0.98	0.02	0.81	0.02	No dam
S_{14}	1.00	0.00	0.81	0.02	No dam
S_{15}	0.89	0.04	0.72	0.03	Milford Dam
S_{16}	0.99	0.02	0.71	0.03	No dam
S_{17}	0.98	0.02	0.70	0.03	Great Works Dam
S_{18}	0.99	0.02	0.69	0.03	No dam
S_{19}	0.92	0.03	0.64	0.04	Veazie Dam
S_{20}	1.00	0.00	0.64	0.04	Start of Estuary
S_{21}	1.00	0.00	0.64	0.04	Estuary
S_{22}	1.00	0.00	0.64	0.04	Estuary
S_{23}	1.00	0.00	0.64	0.04	Estuary
S_{24}	1.00	0.00	0.64	0.04	Estuary
S_{25}	1.00	0.00	0.64	0.04	Estuary
S_{26}	0.92	0.03	0.59	0.04	Estuary
S_{27}	1.00	0.00	0.59	0.04	Estuary
S_{28}	1.00	0.00	0.59	0.04	Estuary
S_{29}	1.00	0.00	0.59	0.04	Estuary
S_{30}	1.00	0.00	0.59	0.04	Estuary
S_{31}	1.00	0.00	0.59	0.04	Estuary
S_{32}	1.00	0.00	0.59	0.04	Estuary
S_{33}	1.00	0.00	0.59	0.04	Estuary
S_{34}	1.00	0.00	0.59	0.04	Estuary
S_{35}	1.00	0.00	0.59	0.04	Estuary
S_{36}	1.00	0.00	0.59	0.04	Estuary
S_{37}	1.00	0.00	0.59	0.04	Estuary
S_{38}	1.00	0.00	0.59	0.04	Estuary
S_{39}	1.00	0.00	0.59	0.04	Estuary
S_{40}	1.00	0.00	0.59	0.04	Estuary
S_{41}	0.97	0.02	0.57	0.04	Estuary
S_{42}	1.00	0.00	0.57	0.04	Bay
S_{43}	0.93	0.03	0.53	0.05	Bay

Table E.6.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the Pleasant River at the Town of Milo in 2011.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
S_{7B}	1.00	0.00	1.00	0.01	No Dam
S_{8B}	0.93	0.03	0.93	0.02	No Dam
S_{9B}	0.88	0.04	0.82	0.02	Howland Dam
S_{10}	1.00	0.00	0.82	0.02	No Dam
S_{11}	1.00	0.00	0.82	0.02	No Dam
S_{12}	0.94	0.03	0.77	0.02	Milford Dam
S_{13}	1.00	0.00	0.77	0.02	No Dam
S_{14}	1.00	0.00	0.77	0.03	Great Works Dam
S_{15}	1.00	0.00	0.77	0.03	Veazie Dam
S_{16}	0.95	0.03	0.73	0.03	Estuary
S_{17}	1.00	0.00	0.73	0.03	Estuary
S_{18}	1.00	0.00	0.73	0.03	Estuary
S_{19}	1.00	0.00	0.73	0.03	Estuary
S_{20}	1.00	0.00	0.73	0.03	Estuary
S_{21}	0.98	0.02	0.72	0.03	Estuary
S_{22}	1.00	0.00	0.72	0.03	Estuary
S_{23}	1.00	0.00	0.72	0.03	Estuary
S_{24}	1.00	0.00	0.72	0.03	Estuary
S_{25}	1.00	0.00	0.72	0.03	Estuary
S_{26}	1.00	0.00	0.72	0.03	Estuary
S_{27}	1.00	0.00	0.72	0.03	Estuary
S_{28}	1.00	0.00	0.72	0.03	Estuary
S_{29}	1.00	0.00	0.72	0.03	Estuary
S_{30}	0.98	0.03	0.70	0.03	Estuary
S_{31}	1.00	0.00	0.70	0.03	Estuary
S_{32}	0.75	0.06	0.53	0.04	Estuary
S_{33}	1.00	0.00	0.53	0.04	Estuary
S_{34}	1.00	0.00	0.53	0.04	Estuary
S_{35}	1.00	0.00	0.53	0.04	Estuary
S_{36}	0.90	0.05	0.47	0.04	Bay
S_{37}	0.95	0.03	0.45	0.04	Bay

Table E.7.- Reach-specific survival rates (S_i) and cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the mouth of the Passadumkeag River in 2010.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
$S_{1...12}$	0.97	0.02	0.97	0.01	No dam
S_{13}	1.00	0.00	0.97	0.01	No dam
S_{14}	0.98	0.02	0.95	0.02	No dam
S_{15}	0.87	0.04	0.83	0.03	Milford Dam
S_{16}	1.00	0.00	0.83	0.03	No dam
S_{17}	1.00	0.00	0.83	0.03	Great Works Dam
S_{18}	1.00	0.00	0.83	0.03	No dam
S_{19}	0.95	0.02	0.79	0.03	Veazie Dam
S_{20}	1.00	0.00	0.79	0.03	Start of Estuary
S_{21}	0.99	0.01	0.78	0.03	Estuary
S_{22}	1.00	0.00	0.78	0.03	Estuary
S_{23}	0.99	0.01	0.77	0.03	Estuary
S_{24}	1.00	0.00	0.77	0.03	Estuary
S_{25}	1.00	0.00	0.77	0.03	Estuary
S_{26}	0.99	0.01	0.76	0.03	Estuary
S_{27}	0.98	0.02	0.75	0.03	Estuary
S_{28}	1.00	0.00	0.75	0.03	Estuary
S_{29}	0.99	0.01	0.74	0.03	Estuary
S_{30}	1.00	0.00	0.74	0.03	Estuary
S_{31}	1.00	0.00	0.74	0.03	Estuary
S_{32}	1.00	0.00	0.74	0.03	Estuary
S_{33}	0.99	0.01	0.73	0.03	Estuary
S_{34}	1.00	0.00	0.73	0.03	Estuary
S_{35}	1.00	0.00	0.73	0.03	Estuary
S_{36}	1.00	0.00	0.73	0.03	Estuary
S_{37}	1.00	0.00	0.73	0.03	Estuary
S_{38}	1.00	0.00	0.73	0.03	Estuary
S_{39}	1.00	0.00	0.73	0.03	Estuary
S_{40}	1.00	0.00	0.73	0.03	Estuary
S_{41}	0.96	0.02	0.70	0.04	Estuary
S_{42}	1.00	0.00	0.70	0.04	Bay
S_{43}	0.99	0.02	0.69	0.04	Bay

Table E.8.- Reach-specific survival rates and (S_i) cumulative survival (with SE estimated using the Delta Method) through each reach for acoustically tagged, hatchery-reared Atlantic salmon smolts released in the mouth of the Passadumkeag River, 2011.

Parameter	S_i	SE of S_i	Cumulative S	SE of Cumulative S	Reach Type
$S_{1...10}$	0.97	0.03	0.97	0.02	No Dam
S_{11}	0.96	0.03	0.92	0.03	No Dam
S_{12}	0.92	0.03	0.85	0.04	Milford Dam
S_{13}	1.00	0.00	0.85	0.04	No Dam
S_{14}	0.94	0.03	0.80	0.04	Great Works Dam
S_{15}	0.98	0.02	0.79	0.05	Veazie Dam
S_{16}	1.00	0.00	0.79	0.05	Estuary
S_{17}	1.00	0.00	0.79	0.05	Estuary
S_{18}	1.00	0.00	0.79	0.05	Estuary
S_{19}	1.00	0.01	0.78	0.05	Estuary
S_{20}	0.94	0.03	0.73	0.05	Estuary
S_{21}	0.98	0.02	0.72	0.05	Estuary
S_{22}	1.00	0.00	0.72	0.05	Estuary
S_{23}	0.99	0.01	0.71	0.05	Estuary
S_{24}	1.00	0.00	0.71	0.05	Estuary
S_{25}	1.00	0.00	0.71	0.05	Estuary
S_{26}	1.00	0.00	0.71	0.05	Estuary
S_{27}	1.00	0.00	0.71	0.05	Estuary
S_{28}	1.00	0.00	0.71	0.05	Estuary
S_{29}	1.00	0.00	0.71	0.05	Estuary
S_{30}	1.00	0.00	0.71	0.05	Estuary
S_{31}	0.99	0.01	0.70	0.05	Estuary
S_{32}	1.00	0.00	0.70	0.05	Estuary
S_{33}	1.00	0.00	0.70	0.05	Estuary
S_{34}	1.00	0.00	0.70	0.05	Estuary
S_{35}	1.00	0.00	0.70	0.05	Estuary
S_{36}	0.99	0.02	0.69	0.06	Bay
S_{37}	0.98	0.04	0.68	0.06	Bay

Appendix F: Reach-specific, maximum-likelihood estimates of mortality (M_i) and instantaneous rates of mortality (Z_d)

Maximum-likelihood estimates of mortality in each reach (M_i) are based on the probability of an individual surviving through the entire reach. Because not all reaches used in modeling smolt survival were equivalent in distance (river kilometers- RKM) it was necessary to standardize mortality by distance in order to examine differences in mortality between reaches of different lengths due to differences in acoustic arrays used in 2010 and 2011. In order to standardize reach-specific survival by distance, we transformed maximum-likelihood estimates of survival using: $Z_{di} = 1 - S_i^{\left(\frac{1}{d}\right)}$, where Z_{di} is an instantaneous rate of mortality (per kilometer, *d*) within each reach (*i*) and S_i is the maximum-likelihood estimate of survival in each reach (i.e. the output from program MARK).

The primary difference between Z_{di} and M_i is that M_i is a one-time, flat-rate of mortality in a reach, regardless reach length, and Z_{di} is a rate that is re-applied to the number of individuals surviving at a standardized interval throughout the reach. So, M_i= 0.10 in a 10-km reach means that reach mortality was 0.10 over 10 kilometers (for example). If we had 100 individuals at the start of end of interval i-1, we would expect about 90 fish to survive using $N_i = N_{i-1} \cdot e^{-Mi}$, where N_i is the number of individuals that survive through reach *i*). By contrast, Z_{di} = 0.10 in a 10-km reach would result in only 40 individuals that survive during reach *i* using $N_i = N_{i-1} \cdot (e^{Z_{di}})^{d-1}$, where *d* is the length of reach *i*. As a more-tangible example, mean reach mortality through the 10-km Milford Dam reach ($\widehat{M}_{\text{MILFORD DAM}}$) in 2010 (SE) was 0.12 (±0.05), and $\hat{Z}_{\text{d, MILFORD DAM}}$ was 0.012 (0.007-0.017). Using Ni-1=100, we would expect about 89 individuals to survive through the reach using either M_i, or Z_{di}. The only difference is that Zdi is standardized, and can thus be used to draw comparisons between mortality through reaches of different lengths.

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